SPACE DIVISION

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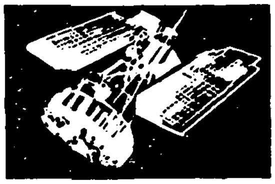
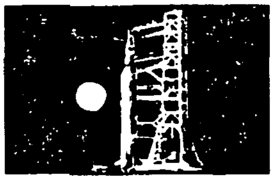
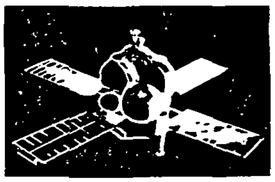
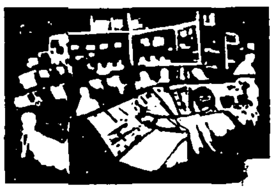

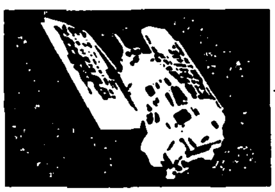
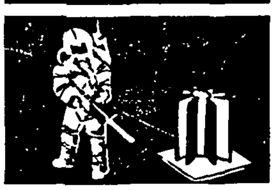
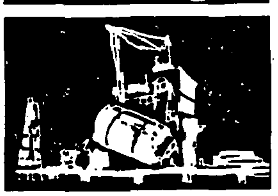

manned space flight nuclear system safety

N73-11698

Volume III
REACTOR SYSTEM PRELIMINARY NUCLEAR SAFETY ANALYSIS

Part 2A
ACCIDENT MODEL DOCUMENT-APPENDIX

GENERAL ELECTRIC

DOCUMENT NO. 72SD4201-3-2A
JANUARY 1972

FINAL REPORT

MANNED SPACE FLIGHT NUCLEAR SYSTEM SAFETY

VOLUME III—REACTOR SYSTEM PRELIMINARY NUCLEAR SAFETY ANALYSIS

PART 2A—ACCIDENT MODEL DOCUMENT—APPENDIX

PERFORMED UNDER

CONTRACT NO. NAS8-26283

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

CONDUCTED BY

SPACE DIVISION
Valley Forge Space Center
P. O. Box 8555 • Philadelphia, Penna. 19101
GENERAL ELECTRIC

I

ABSTRACT

This appendix to the Accident Model Document (Volume III, Part 2) contains the detailed abort sequence trees for the reference zirconium hydride (ZrH) reactor power module that have been generated for each phase of the reference Space Base program mission.

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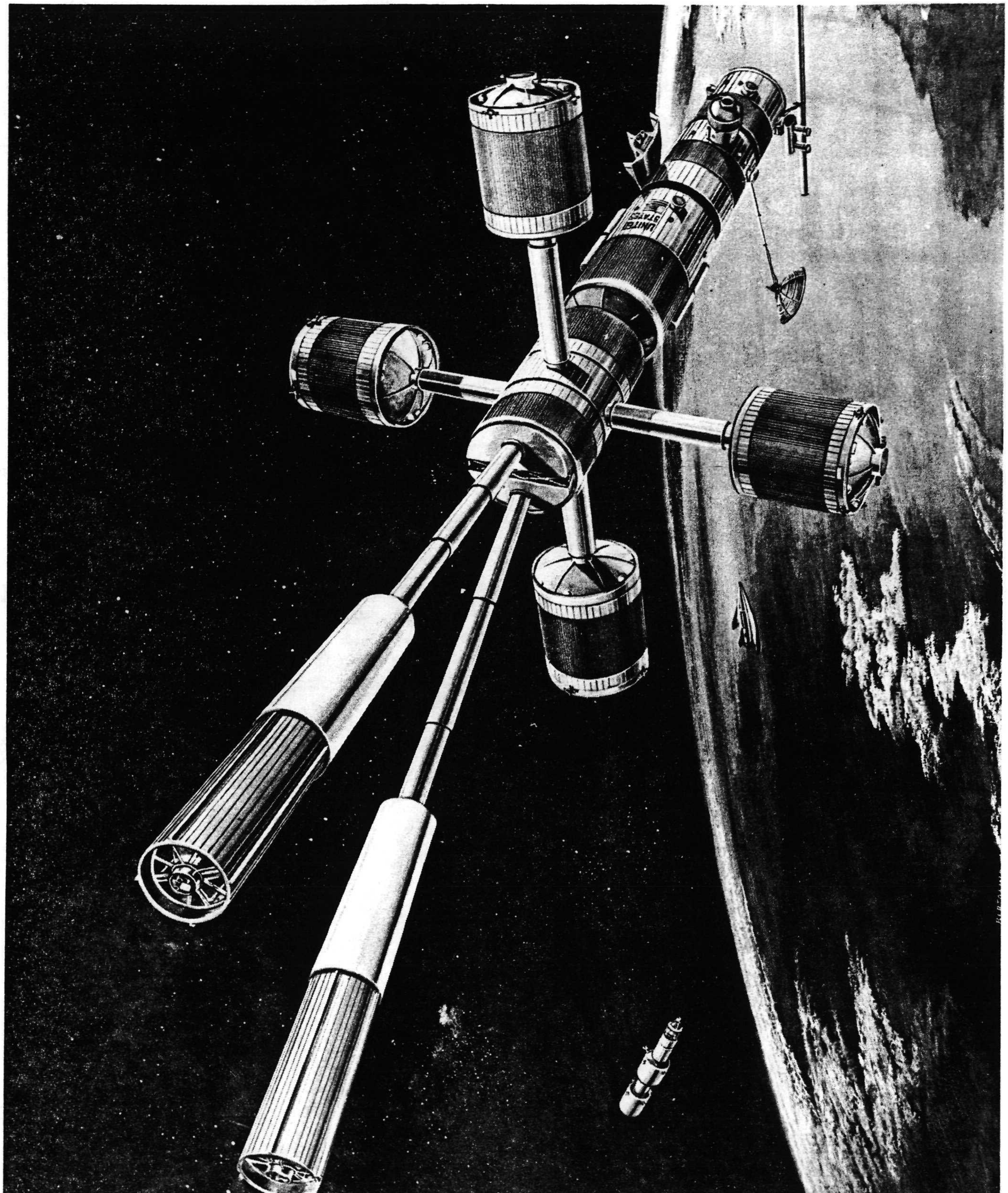

UNITED
STATES

FOREWORD

The establishment and operation of large manned space facilities in earth orbit would constitute a significant step forward in space. Such long duration programs with orbital stay times of up to ten years would benefit the earth's populace and the scientific community by providing:

1. A flexible tool for scientific research.
2. A permanent base for earth oriented applications.
3. A foundation for the future exploration of our universe.

Specifically, the NASA objectives include earth surveys and scientific disciplines of astronomy, bioscience, chemistry, physics and biomedicine, as well as the development of technology for space and earth applications.

Operational and design requirements, of large manned space vehicles, differ from those of the Mercury, Gemini, and Apollo programs. Of particular interest are the radiation survivability and nuclear safety requirements imposed by nuclear power reactors and isotopes and the long term interaction with the natural radiation environment.

The General Electric Company under contract to NASA-MSFC (NAS8-26283) has performed a study entitled "Space Base Nuclear System Safety" for the express purposes of addressing the nuclear considerations involved in manned earth orbital missions. The study addresses both operational and general earth populace and ecological nuclear safety aspects. The primary objective is to identify and evaluate the potential and inherent radiological hazards associated with such missions and recommend approaches for hazard elimination or reduction of risk.

Work performed utilized the Phase A Space Base designs developed for NASA by North American Rockwell and McDonnell Douglas as baseline documentation.

The study was sponsored jointly by NASA's Office of Manned Space Flight, Office of Advanced Research and Technology, and Aerospace Safety Research and Data Institute. It was performed for NASA's George C. Marshall Space Flight Center under the direction of Mr. Walter H. Stafford of the Advanced Systems Analysis Office. He was assisted by a joint NASA and AEC advisory group, chaired by Mr. Herbert Schaefer of NASA's Office of Manned Space Flight.

The results of the study are presented in seven volumes, the titles of which are listed in Table A. A cross-reference matrix of the subjects covered in the various volumes is presented in Table B.

Table A. Manned Space Flight Nuclear System Safety Documentation

Volume		Document No.
I	Executive Summary	
Part 1	Space Base Nuclear Safety	72SD4201-1-1
Part 2	Space Shuttle Nuclear Safety	72SD4201-1-2
II	Space Base Preliminary Nuclear Safety Analysis	
Part 1	Nuclear Safety Analysis (PSAR)	72SD4201-2-1
Part 1A	Appendix-Alternate Reactor Data (CRD)	72SD4201-2-1A
III	Reactor System Preliminary Nuclear Safety Analysis	
Part 1	Reference Design Document (RDD)	72SD4201-3-1
Part 2	Accident Model Document (AMD)	72SD4201-3-2
Part 2A	Accident Model Document - Appendix	72SD4201-3-2A
Part 3	Nuclear Safety Analysis Document (NSAD)	72SD4201-3-3
IV	Space Shuttle Nuclear System Transportation	
Part 1	Space Shuttle Nuclear Safety	72SD4201-4-1
Part 2	Terrestrial Nuclear Safety Analysis	72SD4201-4-2
V	Nuclear System Safety Guidelines	
Part 1	Space Base Nuclear Safety	72SD4201-5-1
Part 2	Space Shuttle/Nuclear Payloads Safety	72SD4201-5-2
VI	Space Base Nuclear System Safety Plan	72SD4201-6
VII	Literature Review	
Part 1	Literature Search and Evaluation	72SD4201-7-1
Part 2	ASRDI Forms	72SD4201-7-2*

*Limited distribution

This study employs the International system of units and where appropriate the equivalent English units are specified in brackets. A list of Conversion Factors and a Glossary of Terms is included in the back of each volume.

Table B. Study Area Cross Reference

*[4] PRIMARY DISCUSSION

○ SUMMARY OR SUPPLEMENTAL DISCUSSION

*Section number is included where appropriate

	DOCUMENTATION													
	VOL I		VOL II		VOL III				VOL IV		VOL V		VOL VI	VOL VII
	72SD4201-1		72SD4201-2		72SD4201-3				72SD4201-4		72SD4201-5		72SD4201-6	72SD4201-7	
STUDY AREAS	Part 1 Space Base - Executive Summary	Part 2 Space Shuttle - Executive Summary	Part 1 PSAR-Space Base	Part 2 Appendix (CRD)	Part 1 RDD-Reactor System, Space Base	Part 2 AMD-Reactor System	Part 2A AMD Appendix	Part 3 NSAD-Reactor System	Part 1 Space Shuttle Nuclear Safety	Part 2 Terrestrial Nuclear Safety Analysis	Part 1 Guidelines - Space Base	Part 2 Guidelines - Space Shuttle	System Safety Plan	Part 1 Literature Search and Evaluation	Part 2 ASRDI Forms
SPACE BASE PROGRAM															
Reference Vehicle Data	○		[3]												
Radiation Limits	○		[4,A]					○	○						
Radiation Environment/Hazards	○		[6]			[3-5]							(5)		
Radiation Effects	○		[6,A]												
Mission Support Nuclear Safety	○		[5]										(6)		
Orbital Operations Nuclear Safety	○		[6,7]						(3-5)						
Design & Operational Considerations	○		[5,7]					○	(3-5)						
Guidelines & Requirements	○		○					○			□	○	(5)		
Reactor System Studies	○		[7]	□											
Terrestrial Safety Analysis	○														
Reference Design					□				(ABC)						
Accident Models & Source Terms						□	□			(2,3)					
Risk Analysis								□		(2,3)					
System Safety Plans													□		
Technology Development Required	○		[8]					○					(7,8)		
SPACE SHUTTLE PROGRAM															
Reference Vehicle Data		○							[ABC]						
Nuclear Payload Integration		○							[3-5]						
Design & Operational Considerations		○	○						[3-6]						
Guidelines and Requirements		○	○						(3-5)		○	□			
Terrestrial Safety Analysis		○			○	○		○	(6)	□					
LITERATURE REVIEW DATA															
Approach and Cross Index														□	
ASRDI Forms															□

ABBREVIATIONS

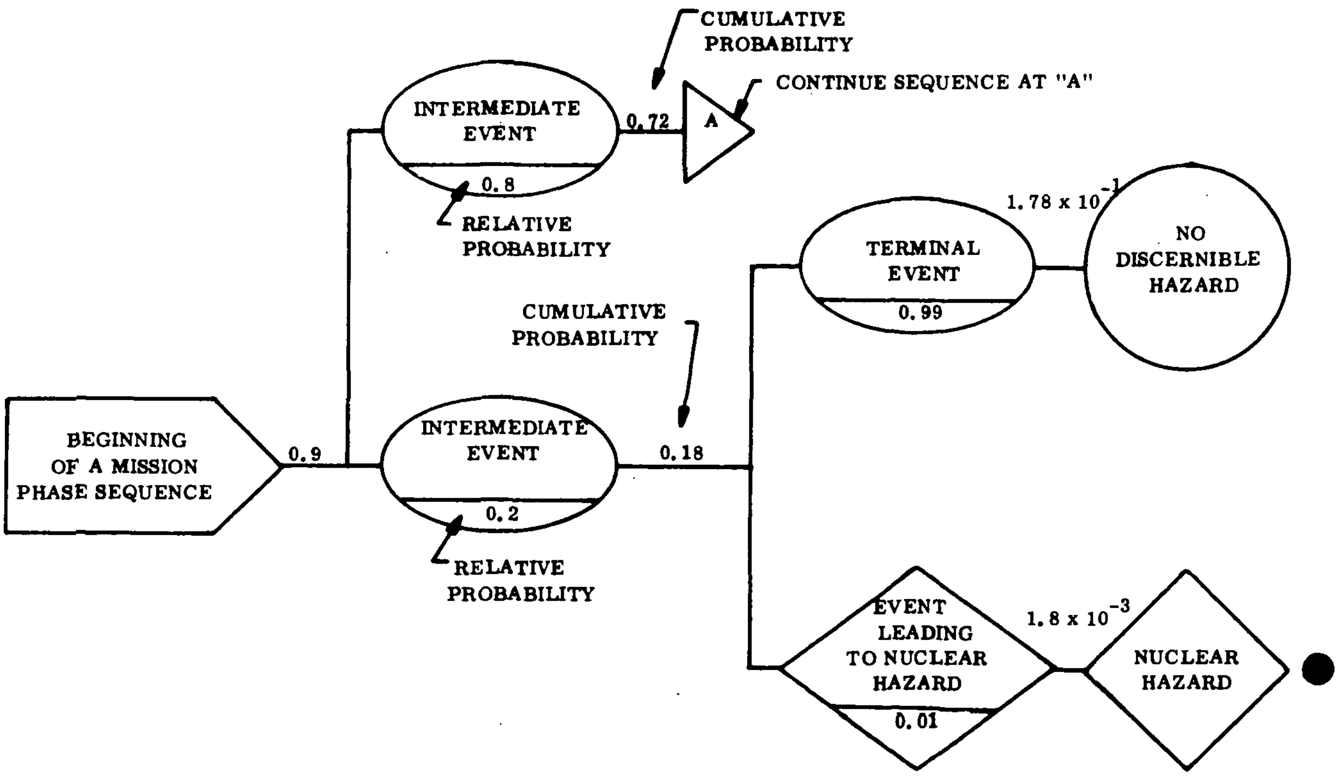
ADM	Add-on Disposal Modules
AEC	Atomic Energy Commission
ALS	Advanced Logistic System (Space Shuttle)
AMD	Accident Model Document
ASRDI	Aerospace Safety Research Data Institute
BOL	Beginning of Life
BPCL	Brayton Power Conversion Loop
BRU	Brayton Rotating Unit
DOD	Department of Defense
DOT	Department of Transportation
ECLS	Environmental Control and Life Support
EM	Electro Magnetic
EOD	Earth Orbital Decay
EOL	End of Life
EOM	End-of-Mission
EPS	Electrical Power System
ETR	Eastern Test Range
EVA	Extra Vehicular Activity
FC	Fuel Capsule
FPE	Functional Program Element
G&C	Guidance and Control
GSE	Ground Support Equipment
HX	Heat Exchanger
ICRP	International Committee on Radiation Protection
IDM	Integral Disposal Module
INT-21	Intermediate Saturn Stages
IR	Infrared
IRV	Isotope Re-Entry Vehicle
IU	Instrument Unit
IVA	Intra Vehicular Activity
KSC	Kennedy Space Center
LCC	Launch Control Center
LD	Lethal Dose (% Probability)
LOX	Liquid Oxygen
LV	Launch Vehicle
MCC	Mission Control Center
MDAC	McDonnell Douglas Corporation
MHW	Multi-Hundred Watt
ML	Mobile Launcher
MPC	Maximum Permissible Concentration
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSS	Mobile Service Structure
NA	Non-Applicable
NAB	Nuclear Assembly Building
NAR	North American Rockwell
NASA	National Aeronautics and Space Administration
NC	Non-Credible
NCRP	National Committee on Radiation Protection
NSAD	Nuclear Safety Analysis Document
OPSD	Orbital Propellant Storage Depot
ORNL	Oak Ridge National Laboratory
PCS	Power Conversion System
PM	Power Module
PSAR	Preliminary Safety Analysis Report
RAD	Radiation Absorbed Dose
RCS	Reaction Control System
RDD	Reference Design Document
REM	Roentgen Equivalent Man
RMU	Remote Maneuvering Unit
RNS	Reusable Nuclear Shuttle
R/S	Reactor/Shield
RSO	Radiation Safety Officer
RTG	Radioisotope Thermoelectric Generator
SB	Space Base
SAR	Safety Analysis Report
SEHX	Separable Heat Exchanger
S-IC	First Stage of Saturn V
S-II	Second Stage of Saturn V
SNAP	Space Nuclear Auxiliary Power
SNAPTRAN	Space Nuclear Auxiliary Power Transient
TAC	Turbine Alternator Compressor
TEM	Thermoelectric Electro Magnetic Pump
TLD	Thermo Luminescent Dosimeter
USAF	United States Air Force
VAB	Vehicle Assembly Building

APPENDIX D
MISSION ABORT SEQUENCE TREES

This appendix contains the detailed abort sequence trees for the reference zirconium hydride (ZrH) reactor power module that have been generated for each phase of the reference Space Base program mission. These trees are graphical representations of causal sequences. Each tree begins with the phase identification and the dichotomy between success and failure. The success branch shows the mission phase objective as being achieved. The failure branch is subdivided, as conditions require, into various primary initiating abort conditions. From each of these initiating events, the causal chain is followed through to either (1) a nuclear hazard, (2) a condition that results in "no discernible hazard", or (3) a successful repair or correction that leads back to the success branch. In this manner, the sequence trees show how the particular events and their "relative probabilities" are determined. Terminology used in the abort sequence trees is defined in the Glossary of Terms.

The abort sequence trees were generated without considering probabilities; all events that seemed even remotely possible were considered. Only upon completion of the trees were probabilities considered. The probability of a given accident occurring in any phase of the mission was derived from experimental data where available, and from engineering judgement where such data was lacking.

The abort sequence trees use five graphical symbols as illustrated on the next page.



1. The oval - used for initiating events and for intermediate and terminal events in which a nuclear hazard has not occurred.

2. The diamond - used for intermediate and terminal events in which a nuclear hazard is the direct result or to indicate a nuclear hazard itself (indicated by a large dot placed next to the diamond).

3. The circle - used for terminal events which result in "no discernible hazard" to the populace.

4. The triangle - used for indicating where a sequence is to be continued.

5. The pentagon - used for the beginning of a mission phase sequence.

"Relative probability" is defined as the probability of a particular event to occur given a defined set of choices; cumulative probability (sometimes referred to as "mission probability") is the overall probability of a sequence of events occurring (product of relative probabilities of the individual events along the path) during the mission (starting from prelaunch). The relative probability of a particular event occurring is placed in the lower section of the event box. If the relative probability of an event is 1.0, no probability is shown in the event box.

Parallel events in the sequence trees are taken as mutually exclusive. Therefore, the sum of the relative probabilities of parallel events is one. It is assumed that event probabilities of less than 10^{-12} have a negligible effect on risk and, hence, individual branches of the abort sequence trees are terminated and deemed "Non-credible".

The following list indicates which figures are associated with the particular mission phases:

	Mission Phase	Figure No.	Page No.
1.	Prelaunch	D-1 and D-2	D-5 and D-6
2.	Launch/Ascent	D-3 to D-10	D-7 thru D-14
3.	Orbital Operations	D-11 to D-49	D-15 thru D-53
4.	Reactor Disposal	D-50 to D-127	D-54 thru D-131

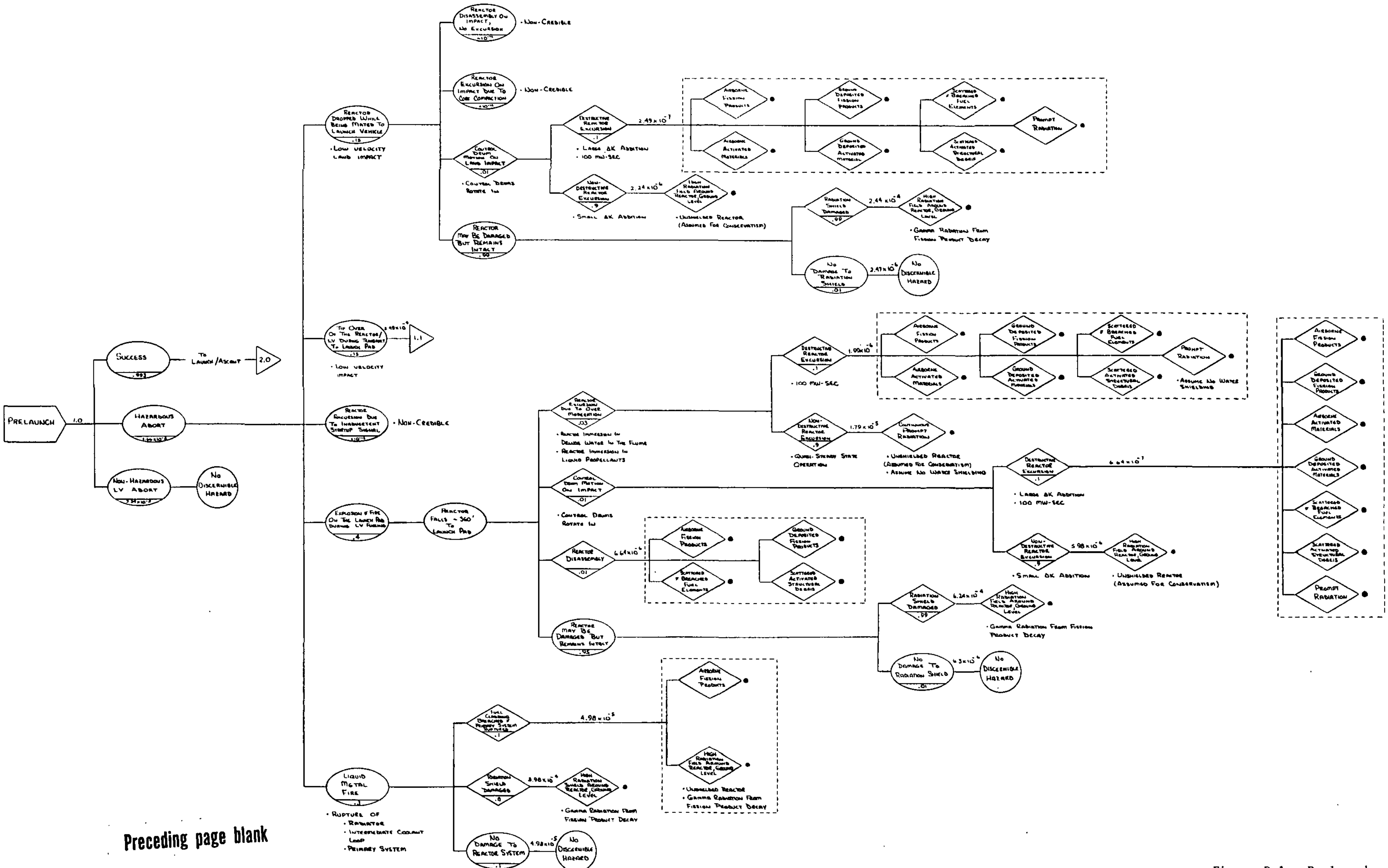


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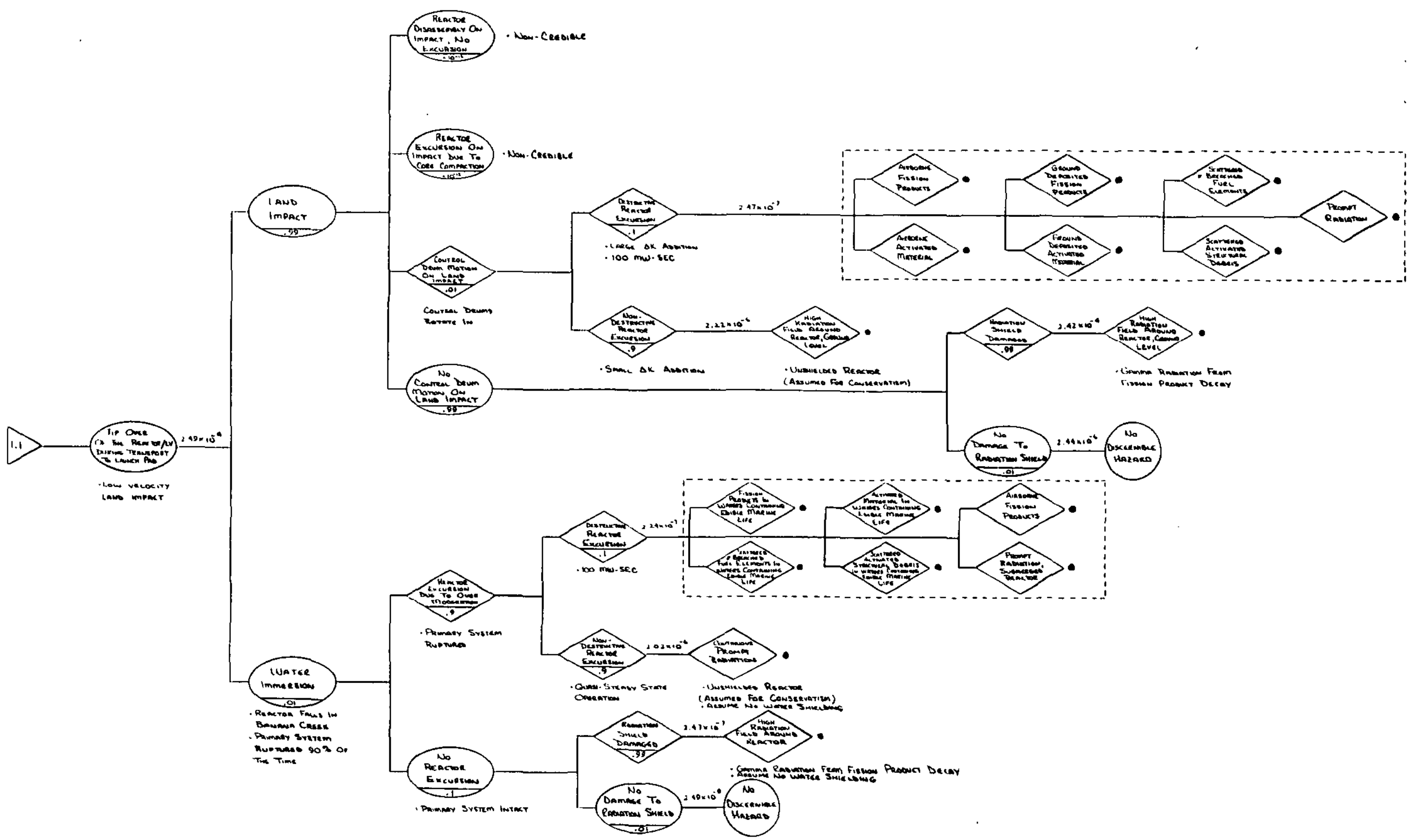
Figure D-1. Prelaunch

D-5 A

B



D-6 B

Figure D-2. Tip Over of the Reactor/Launch Vehicle During Transport To Launch Pad

D-6 A

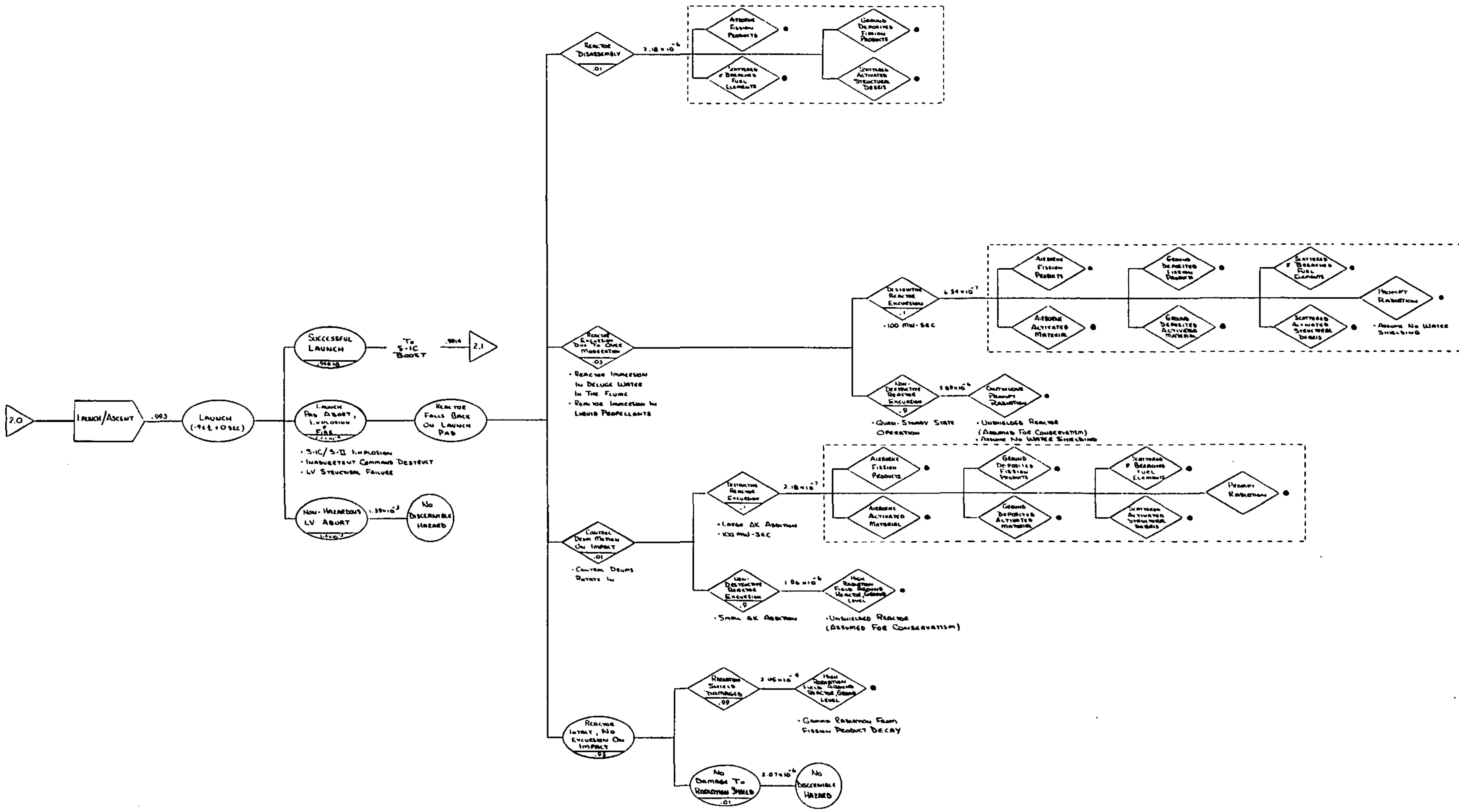


Figure D-3. Launch (-9 ≤ t ≤ 0 sec)

D-7 A

B

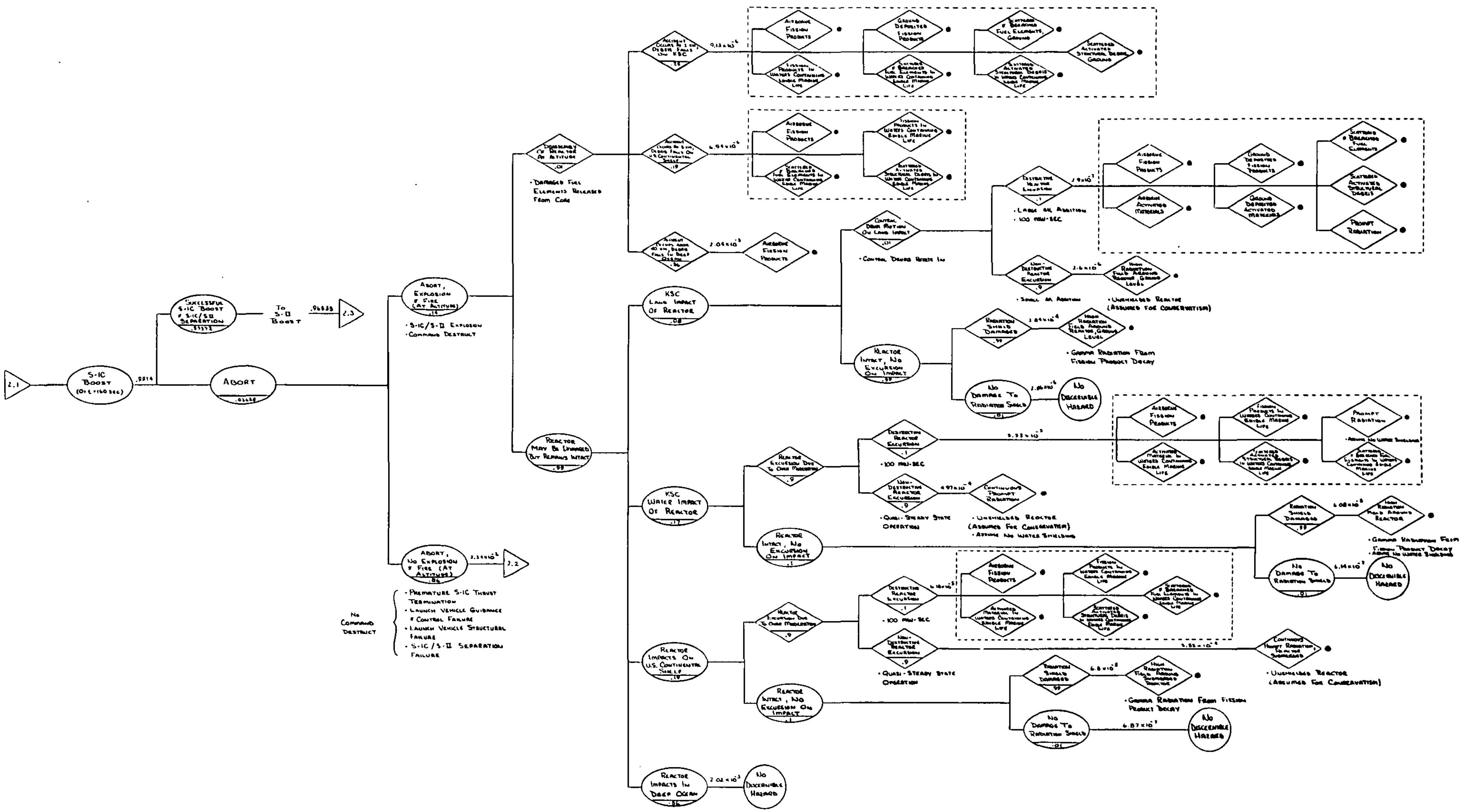


Figure D-4. S-IC Boost (0 ≤ t ≤ 160 sec)

D-8 A B

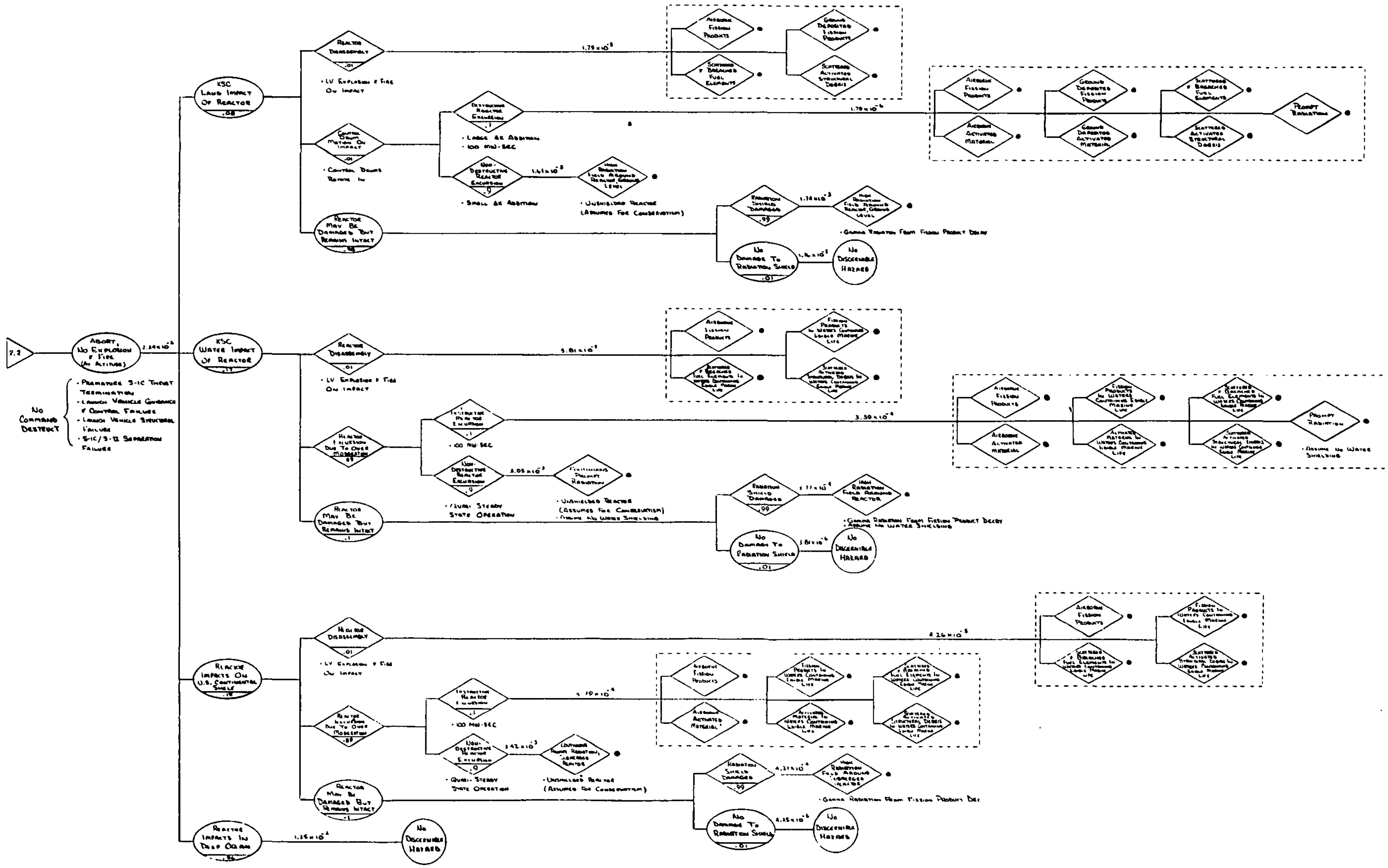


Figure D-5. Abort, No Explosion and Fire at Altitude (S-IC Boost)

D-9 A

15

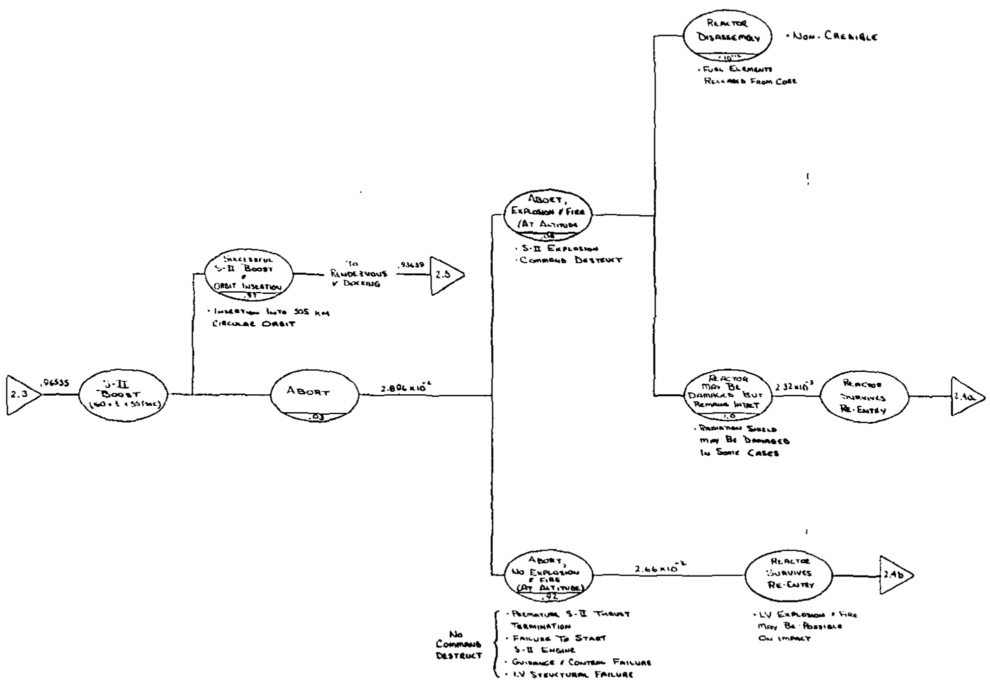
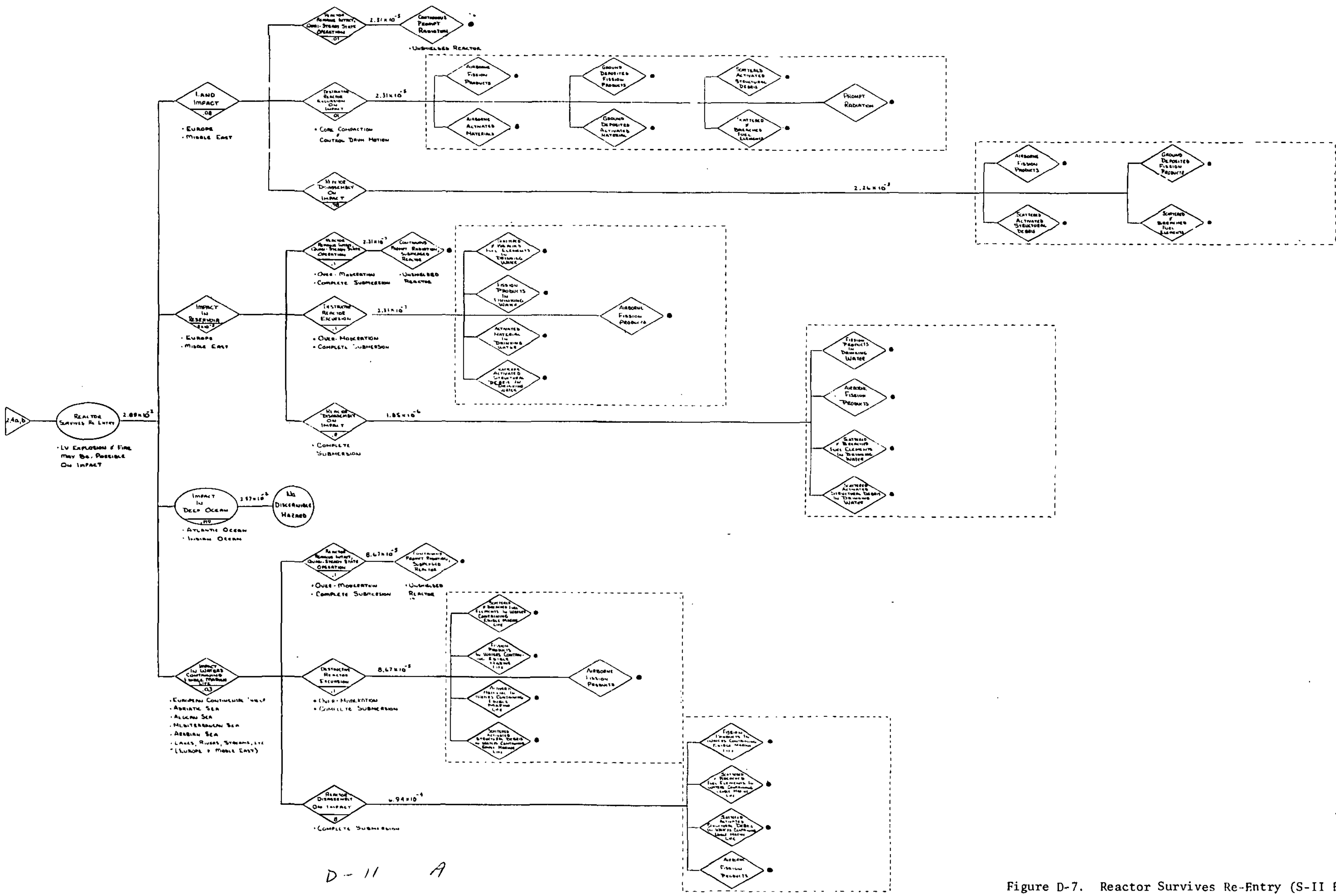


Figure D-6. S-II Boost (160 ≤ t ≤ 557 sec)

D-10- A

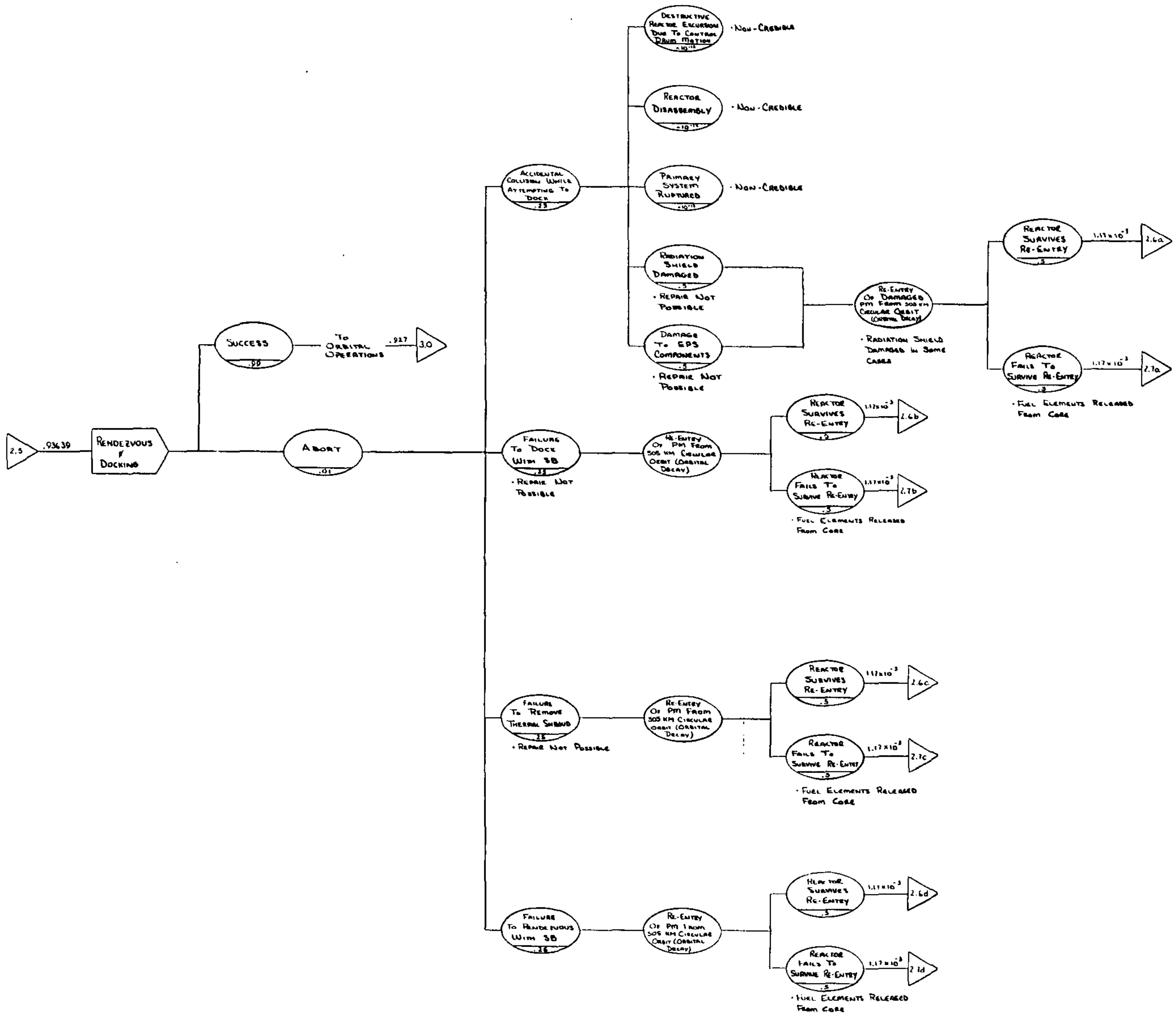
B



D - 11 A

Figure D-7. Reactor Survives Re-Entry (S-II Boost)

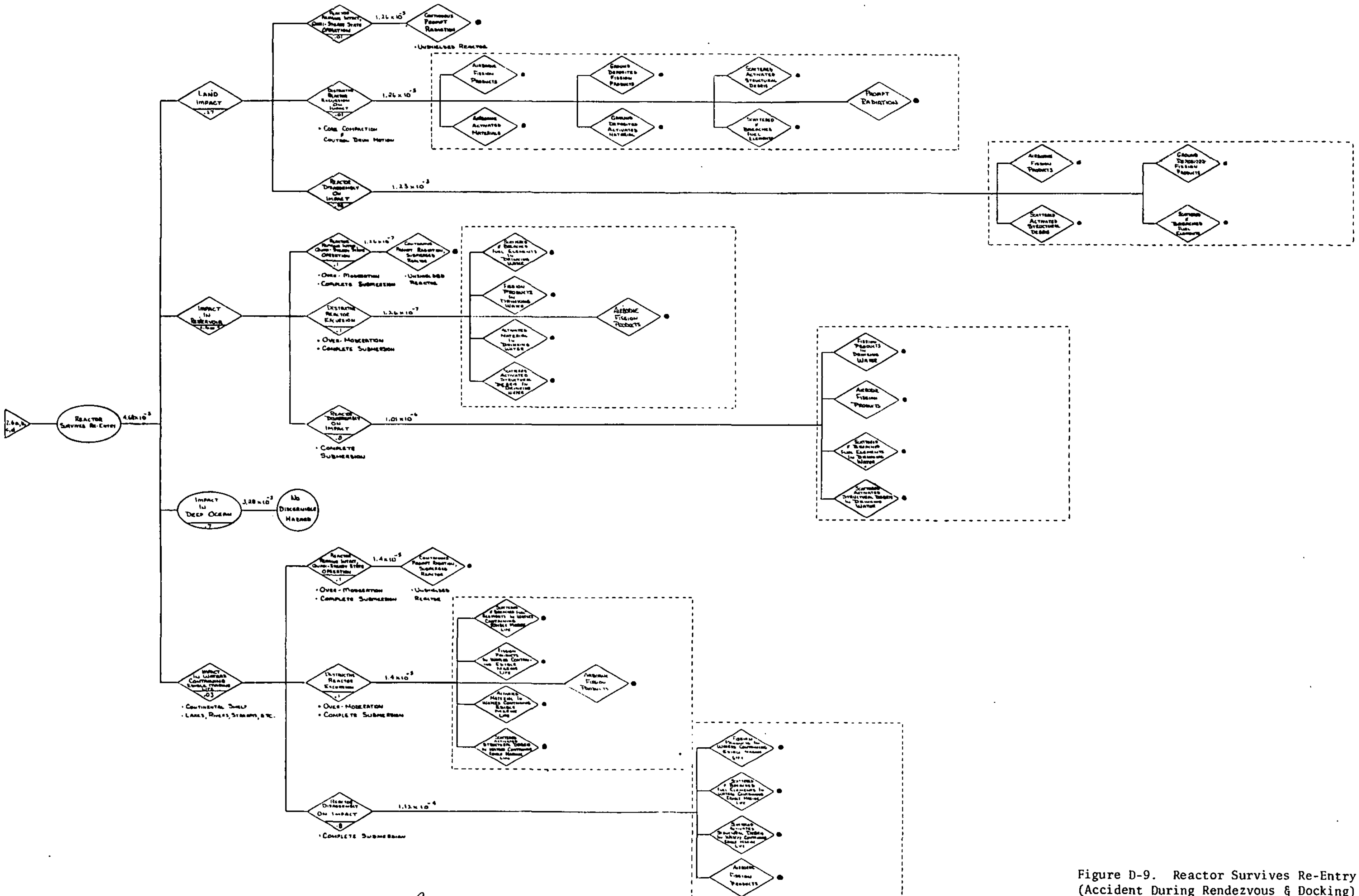
B



D-12 A

B

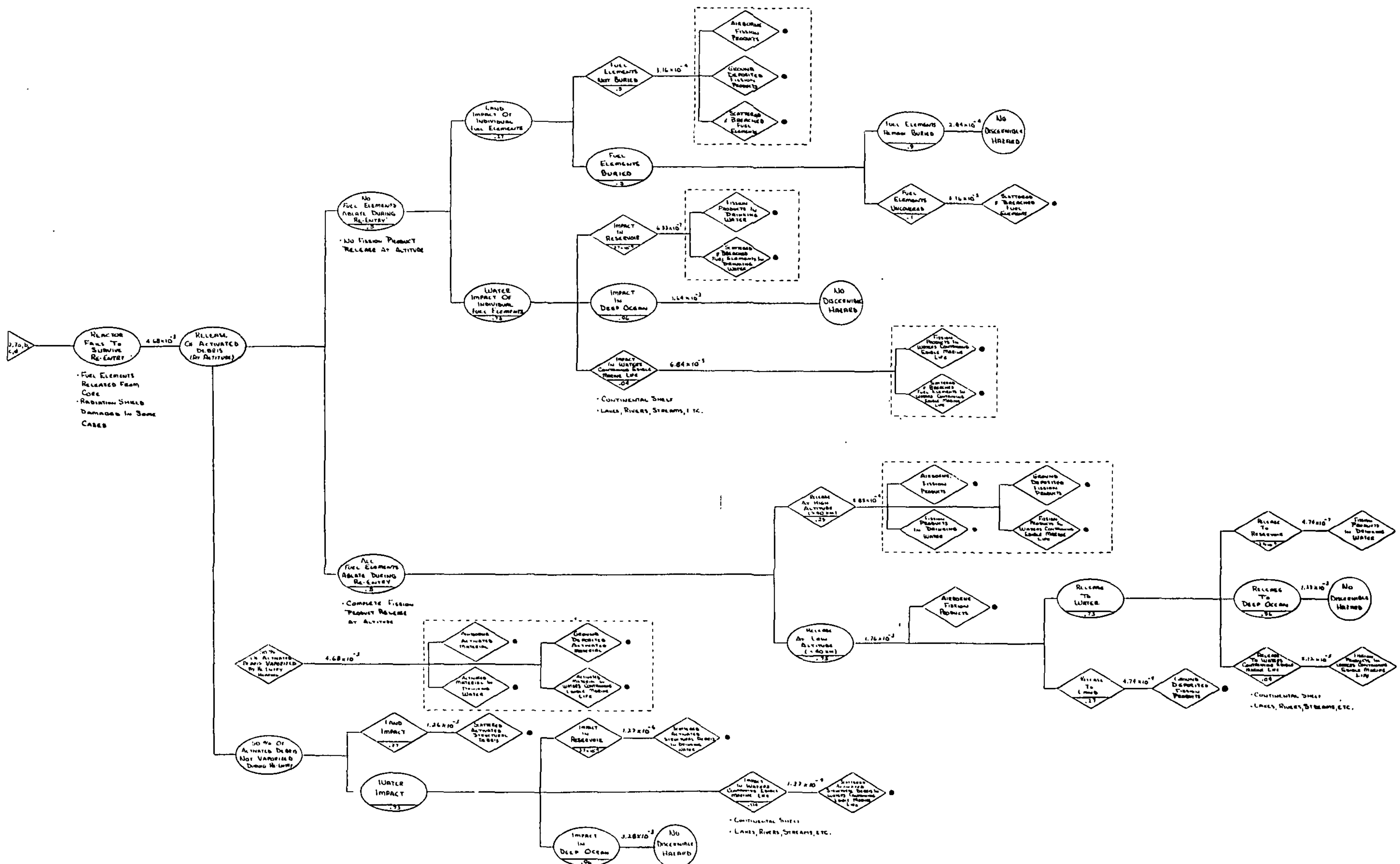
Figure D-8. Rendezvous & Docking



D-13 A

B

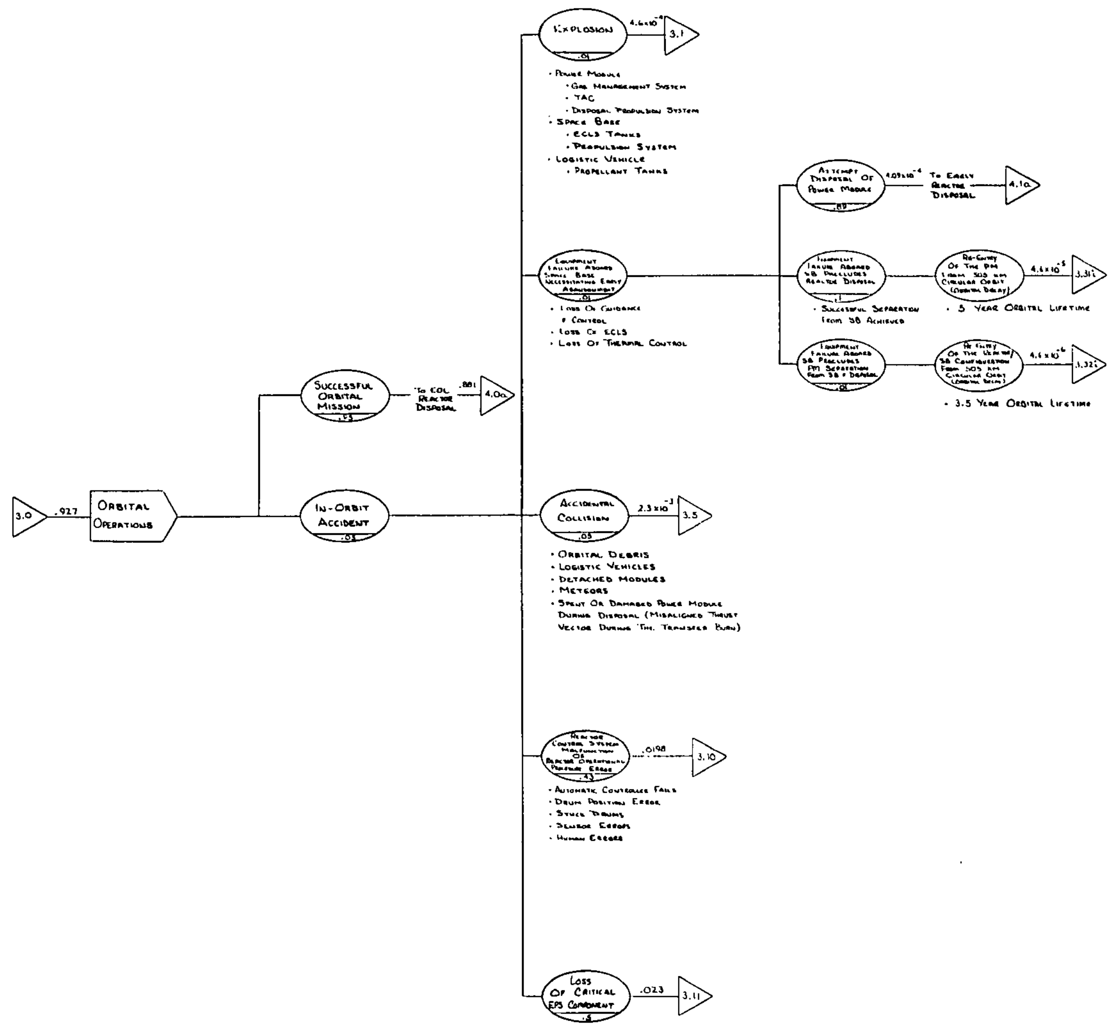
Figure D-9. Reactor Survives Re-Entry
(Accident During Rendezvous & Docking)



D- 14 A

Figure D-10. Reactor Fails to Survive Re-Entry
(Accident During Rendezvous & Docking)

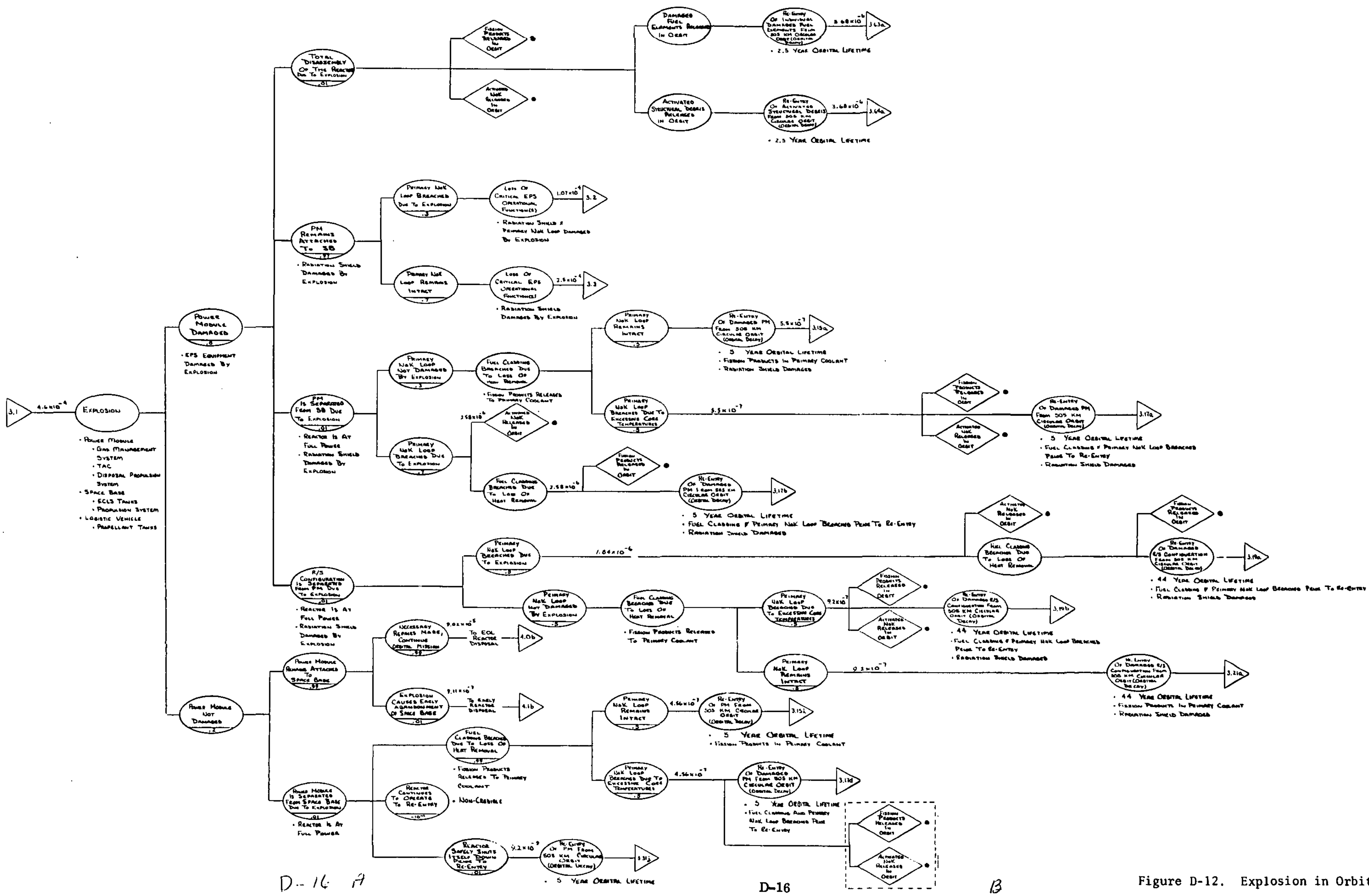
B



D-15 A

B

Figure D-11. Orbital Operations



D-16 A

B

Figure D-12. Explosion in Orbit

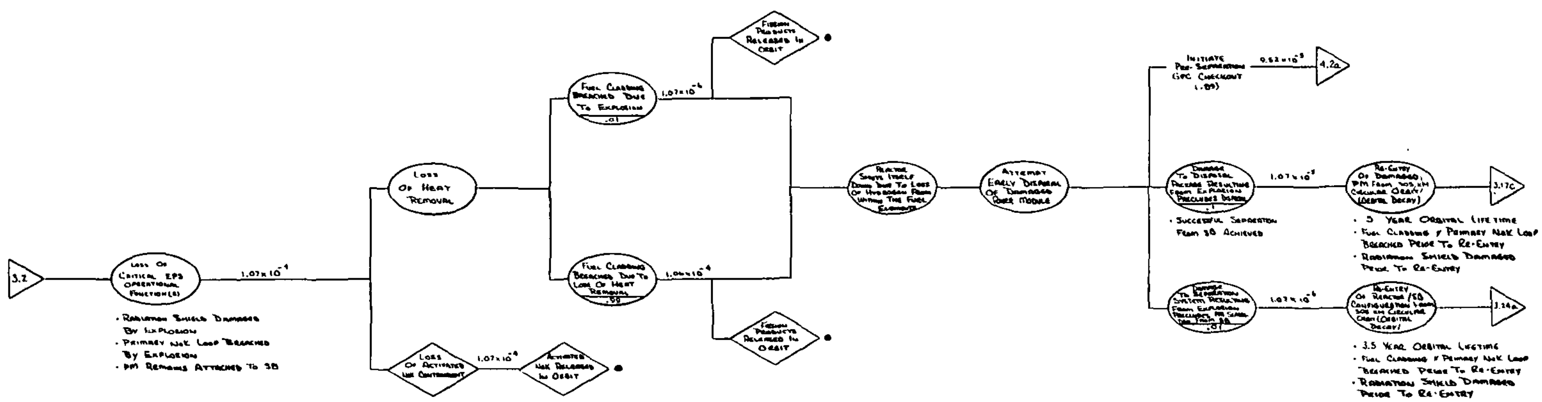
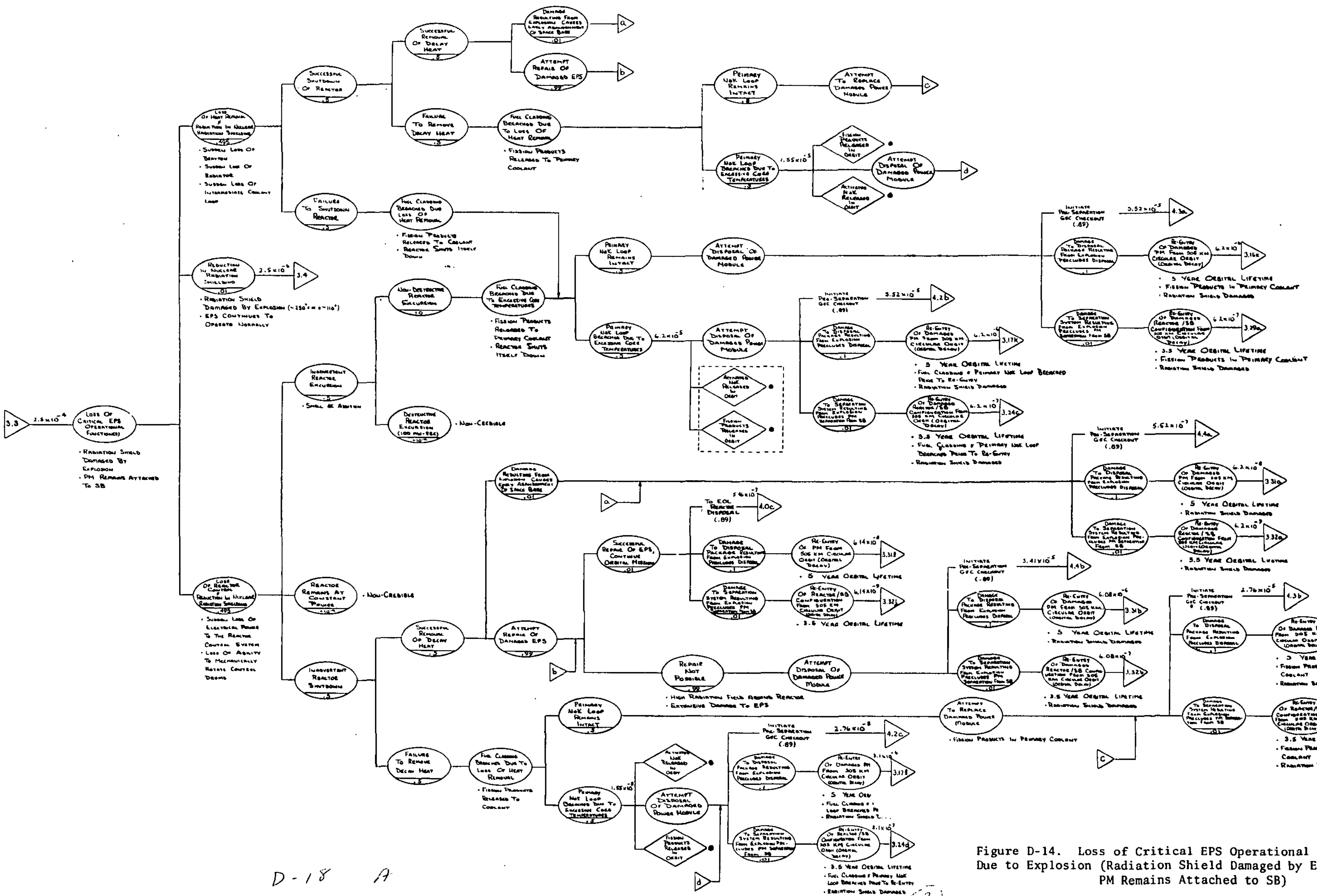


Figure D-13. Loss of Critical EPS Operational Function(s) Due to Explosion (Radiation Shield & Primary NaK Loop Breached by Explosion, PM Remains Attached to SB)

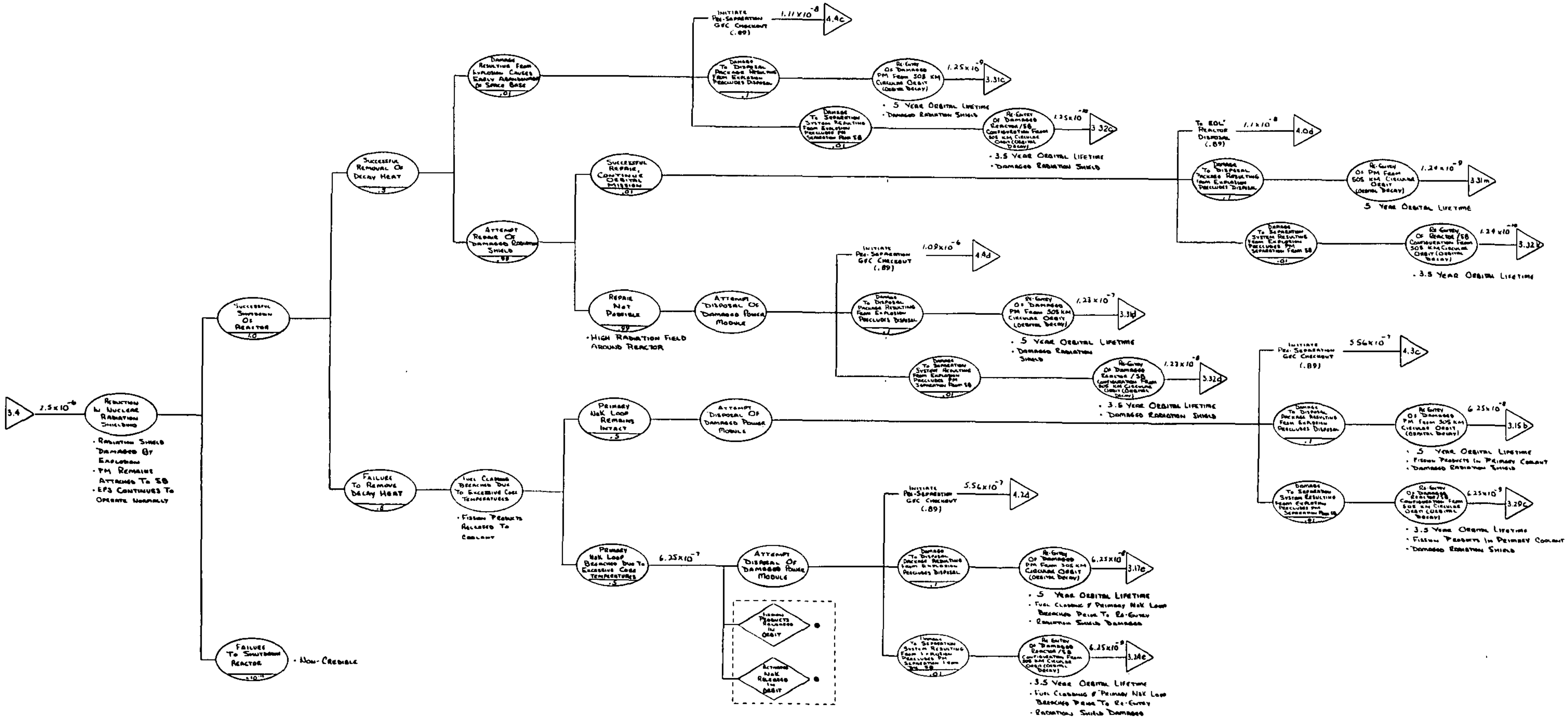
D - 17 A B



D-18 A

Figure D-14. Loss of Critical EPS Operational Function(s) Due to Explosion (Radiation Shield Damaged by Explosion, PM Remains Attached to SB)

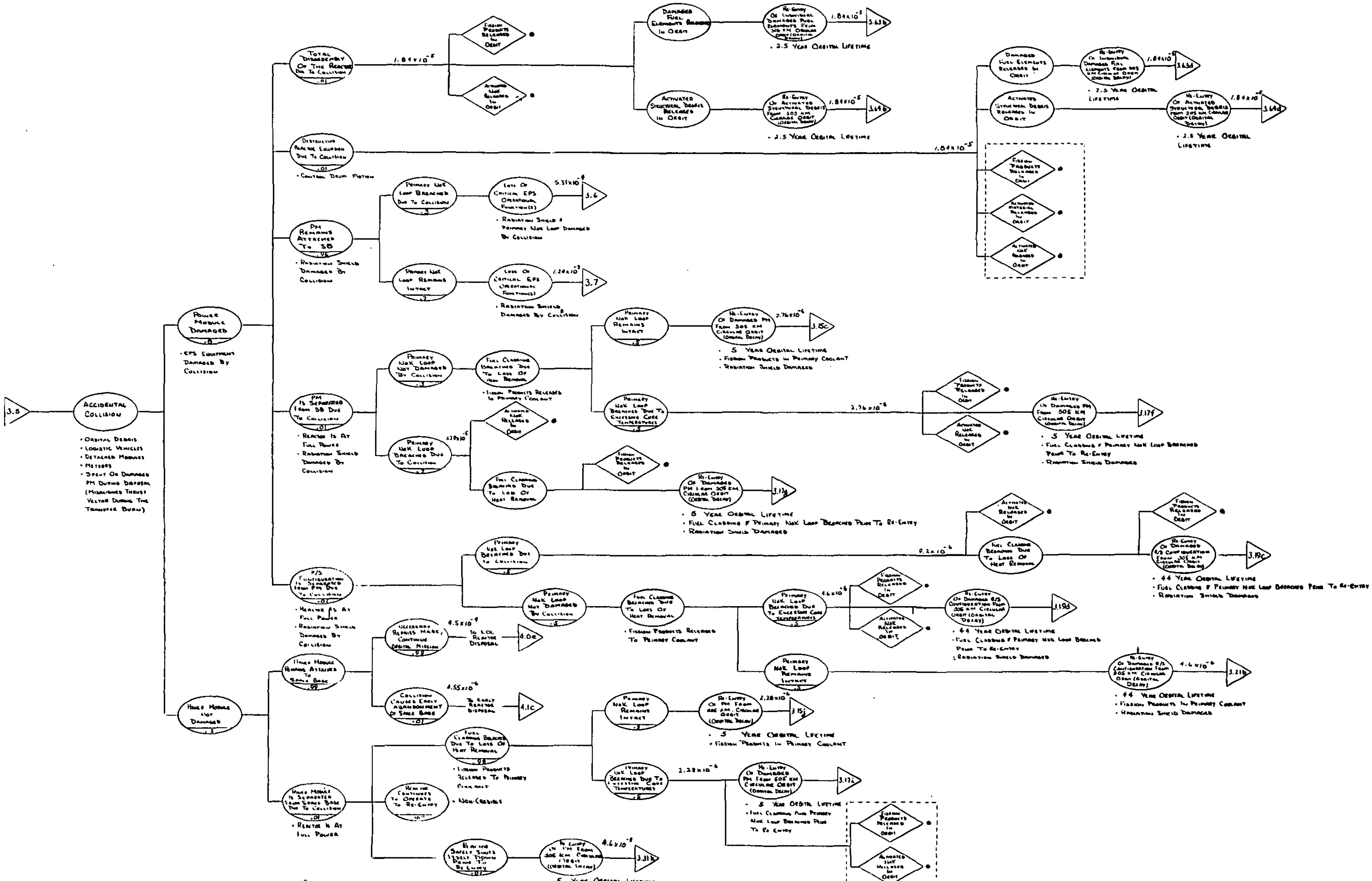
13



D-19 A

Figure D-15. Reduction in Nuclear Radiation Shielding (Radiation Shield Damaged by Explosion, PM Remains Attached to SB)

B



D-.20 A

B

Figure D-16. Accidental Collision in Orbit

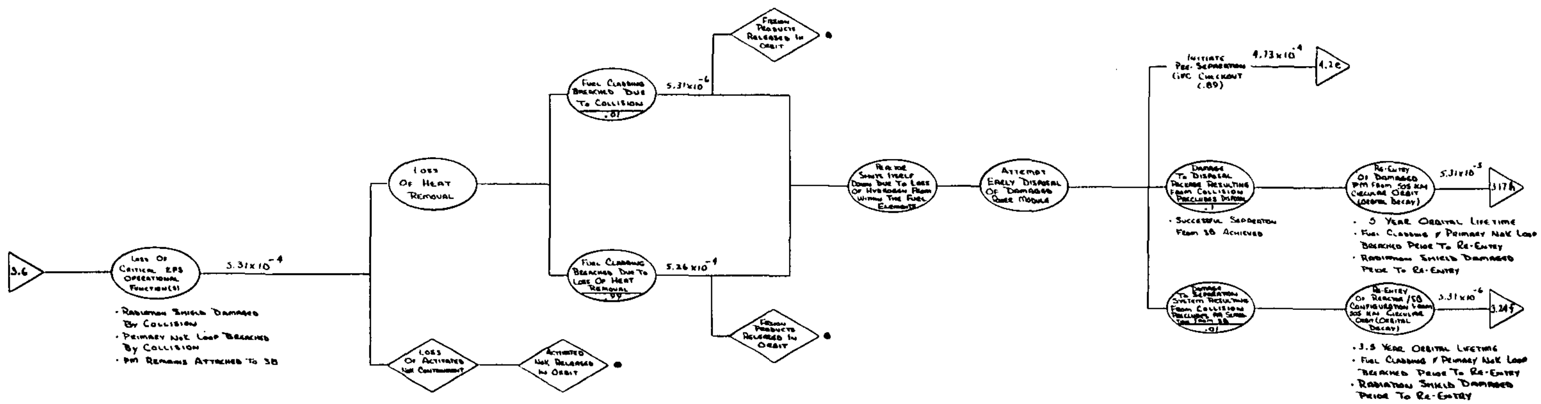
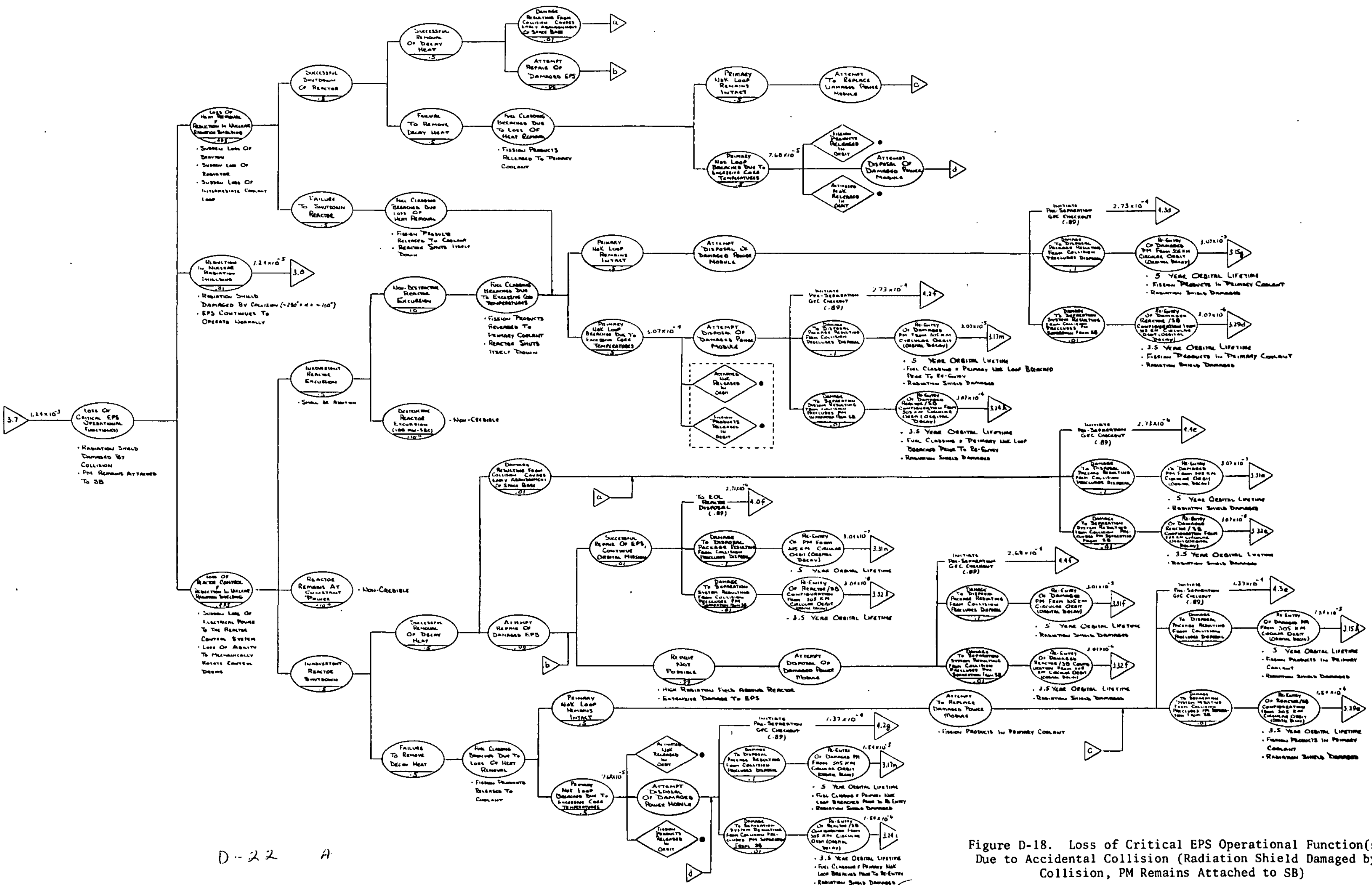


Figure D-17. Loss of Critical EPS Operational Function(s) Due to Accidental Collision (Radiation Shield & Primary NaK Loop Breached by Collision, PM Remains Attached to Space Base)

D-21 A

(13.)



D-22 A

Figure D-18. Loss of Critical EPS Operational Function(s) Due to Accidental Collision (Radiation Shield Damaged by Collision, PM Remains Attached to SB)

(B)

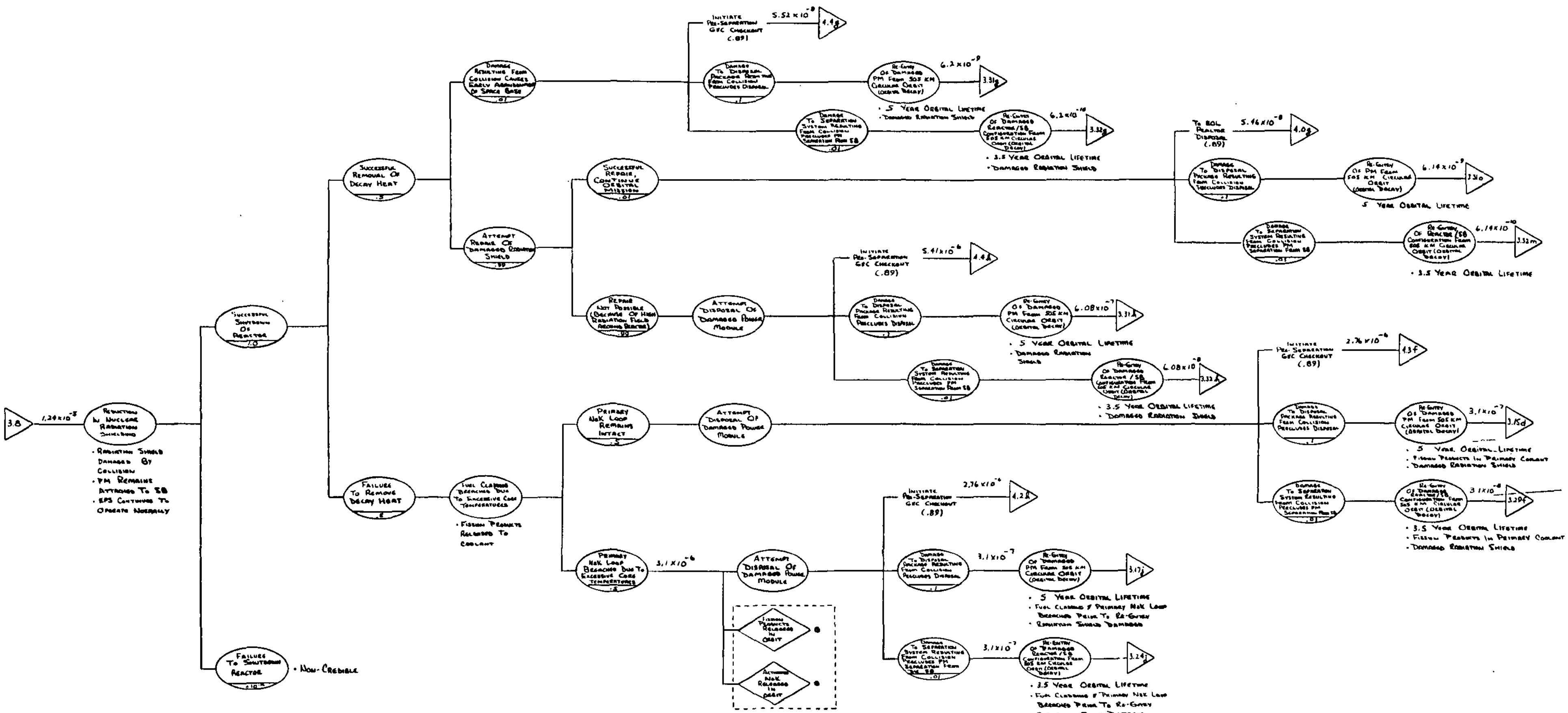


Figure D-19. Reduction in Nuclear Radiation Shielding (Radiation Shield Damaged by Accidental Collision, PM Remains Attached to SB)

D-23 A

B

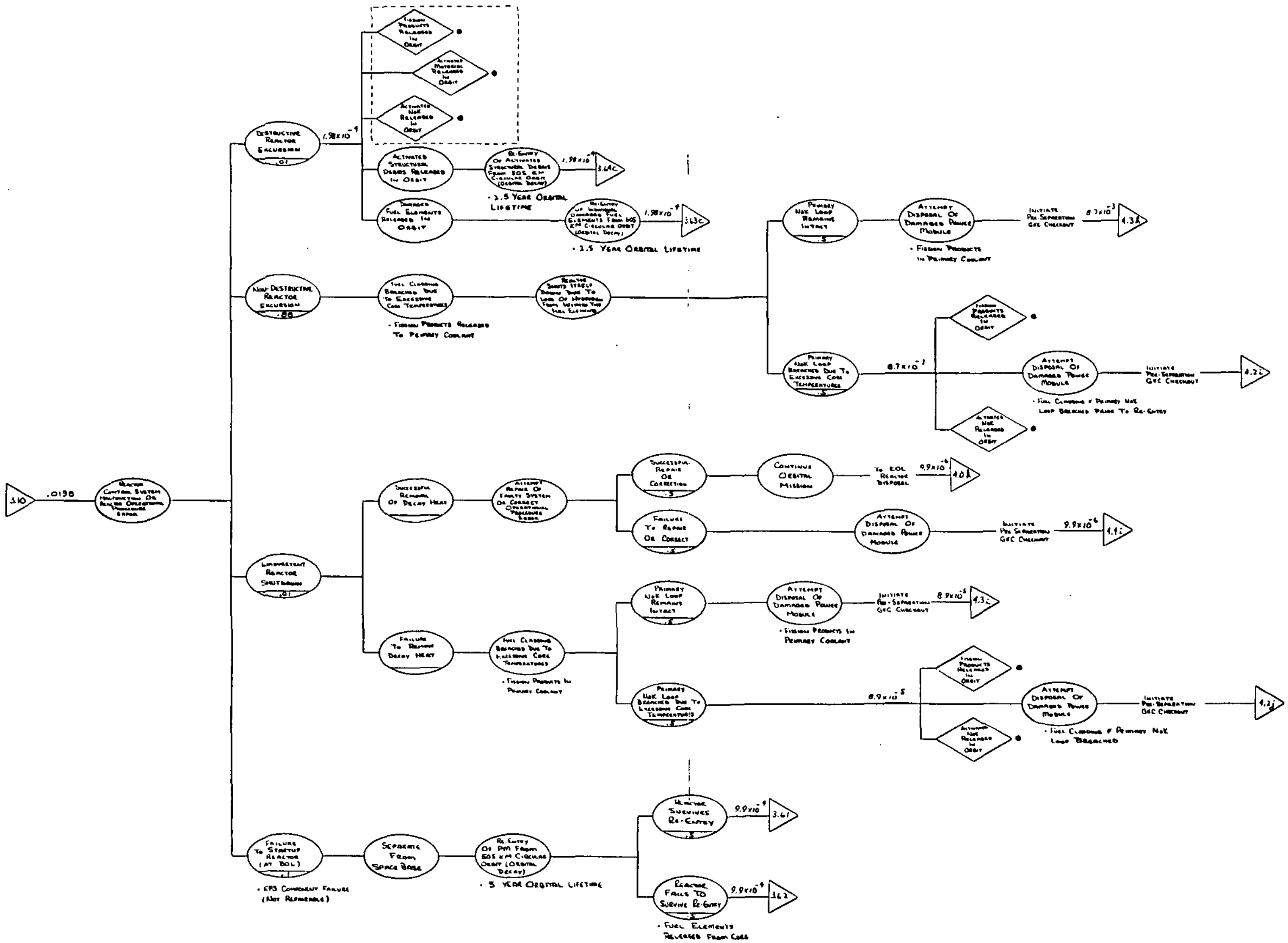
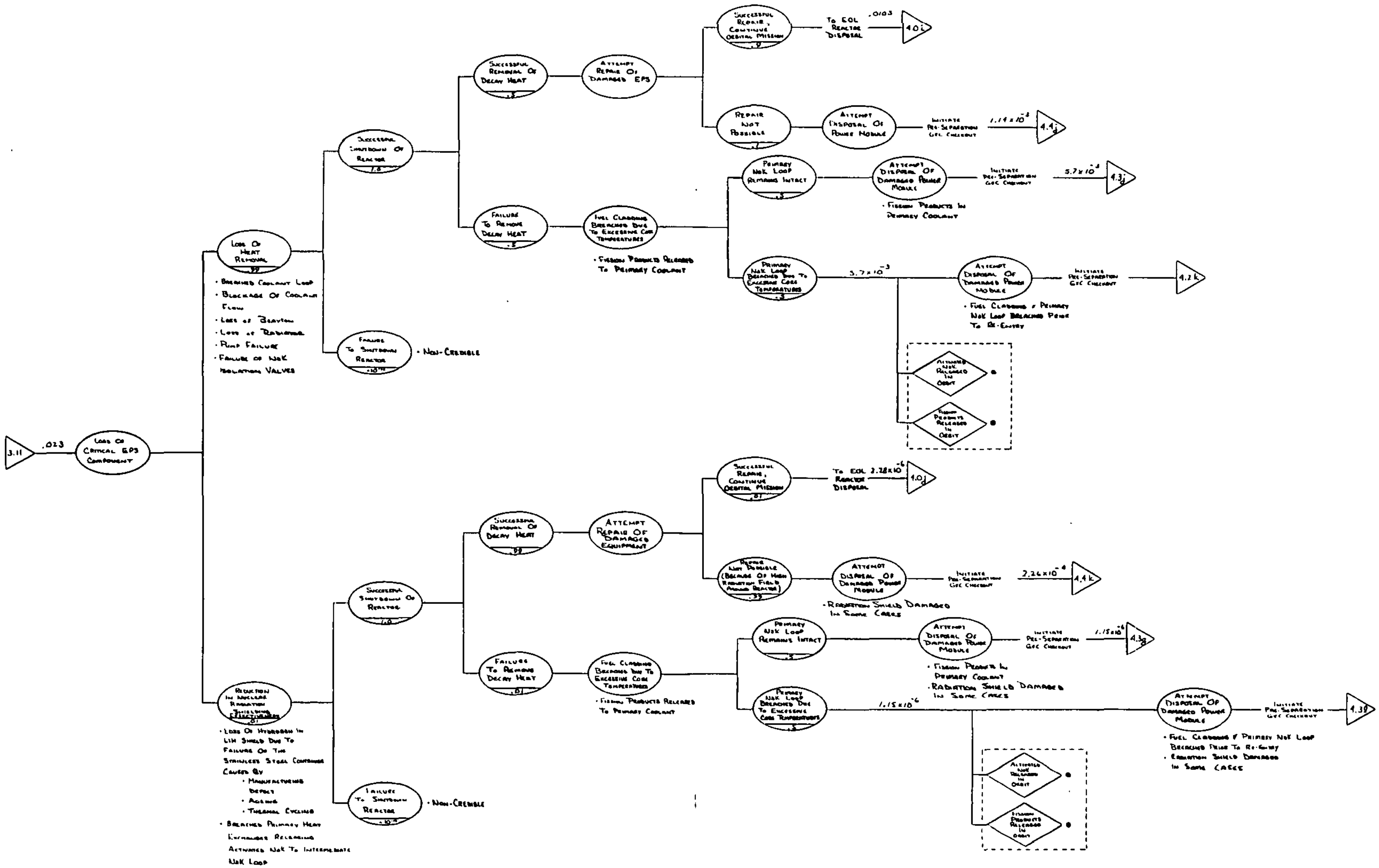


Figure D-20. Reactor Control System Malfunction or Reactor Operational Procedure Error

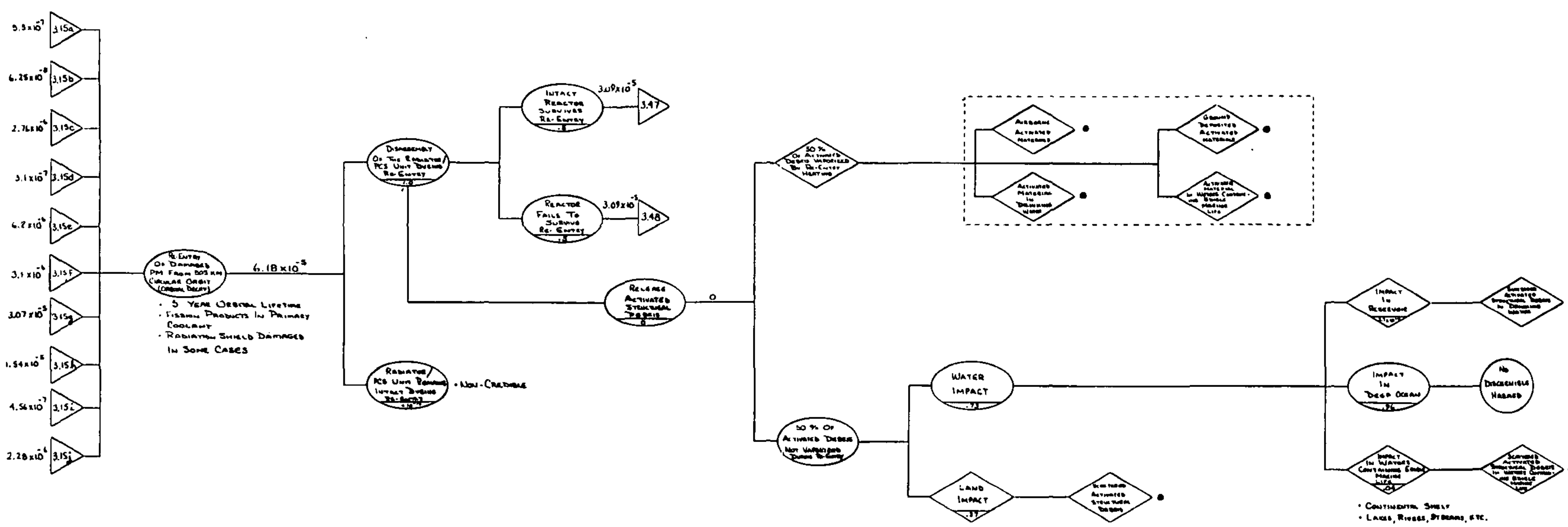
D-24 A



D-25 A

Figure D-21. Loss of Critical EPS Component in Orbit

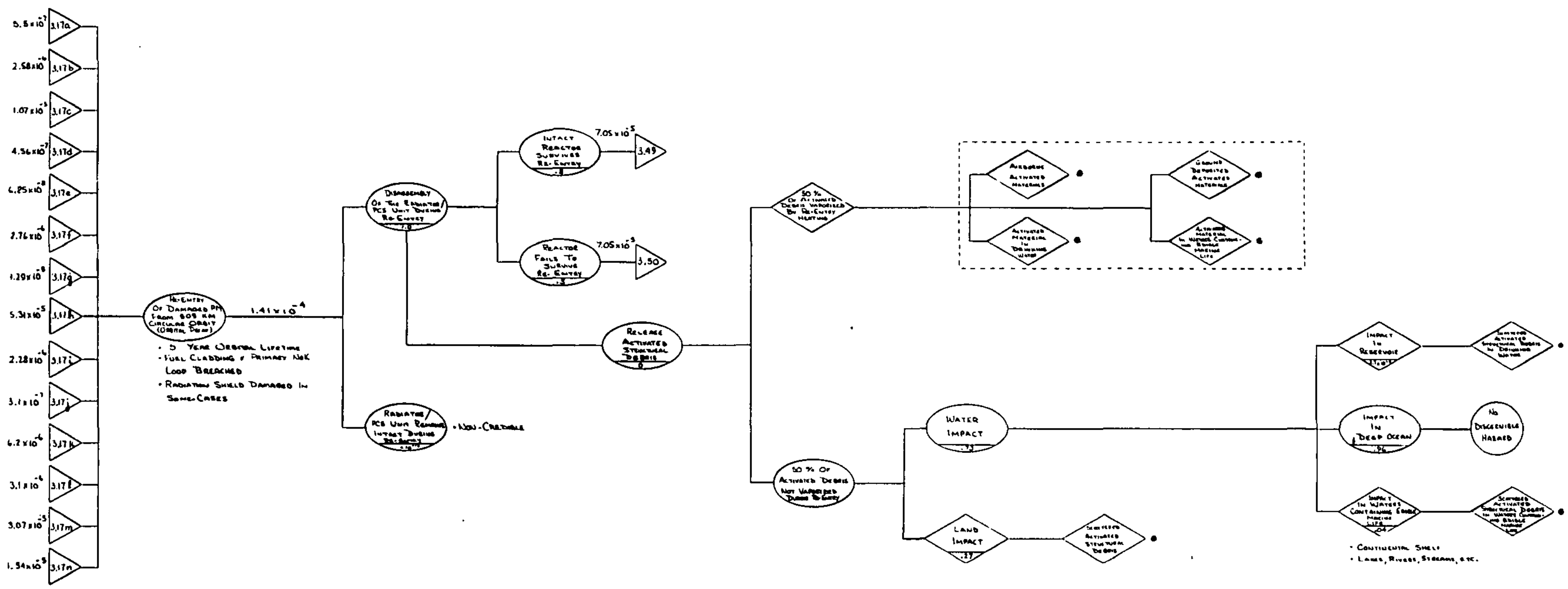
(B)



D - 26 A

Figure D-22. Re-Entry of Damaged PM from 500 km Circular Orbit, Orbital Decay (Fission Products in Primary Coolant, Radiation Shield Damaged in Some Cases)

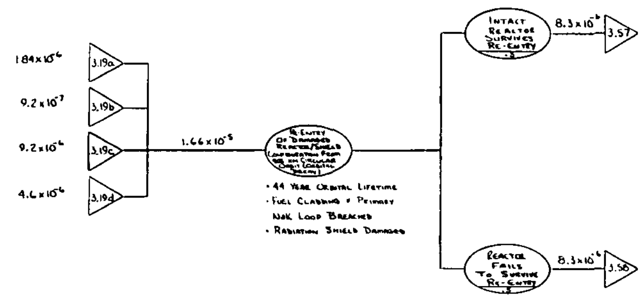
B



D-27 A

Figure D-23. Re-Entry of Damaged PM from 500 km Circular Orbit, Orbital Decay (Fuel Cladding & Primary NaK Loop Breached, Radiation Shield Damaged in Some Cases)

(B)



D-28 A

Figure D-24. Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay (Fuel Cladding & Primary NaK Loop Breached, Radiation Shield Damaged)

B

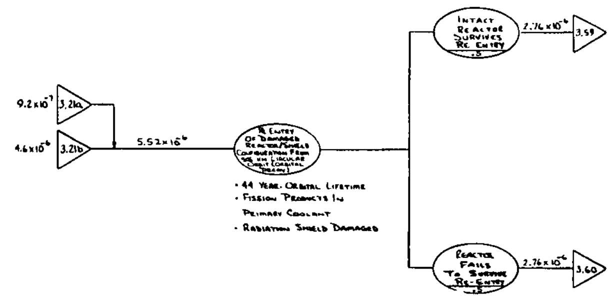


Figure D-25. Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay (Fission Products in Primary Coolant, Radiation Shield Damaged)

D-29 A

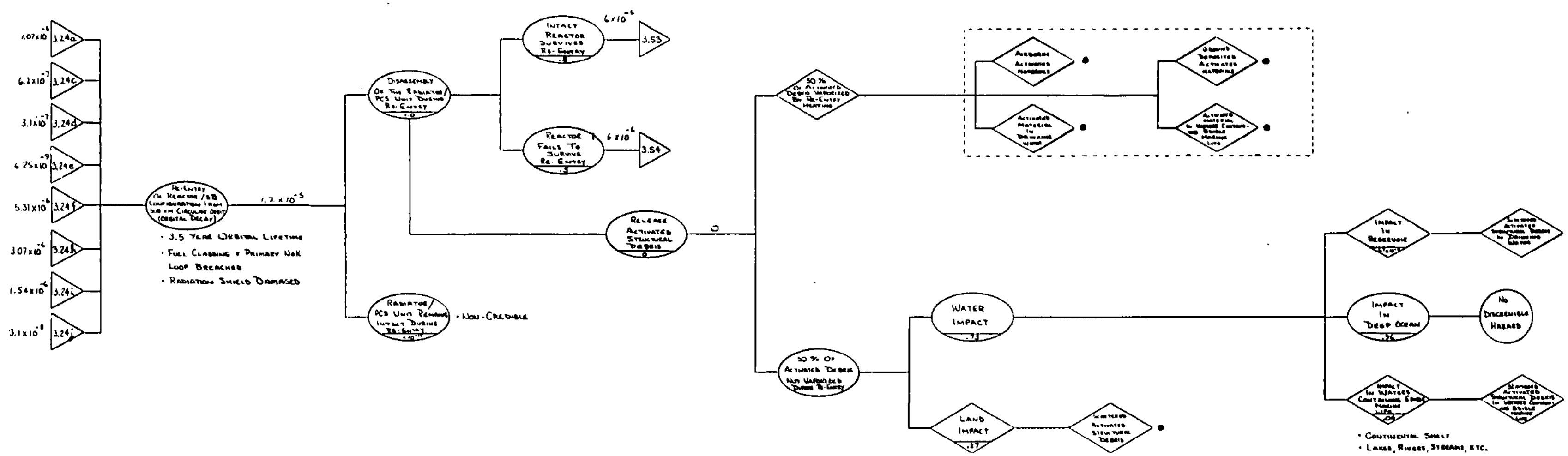
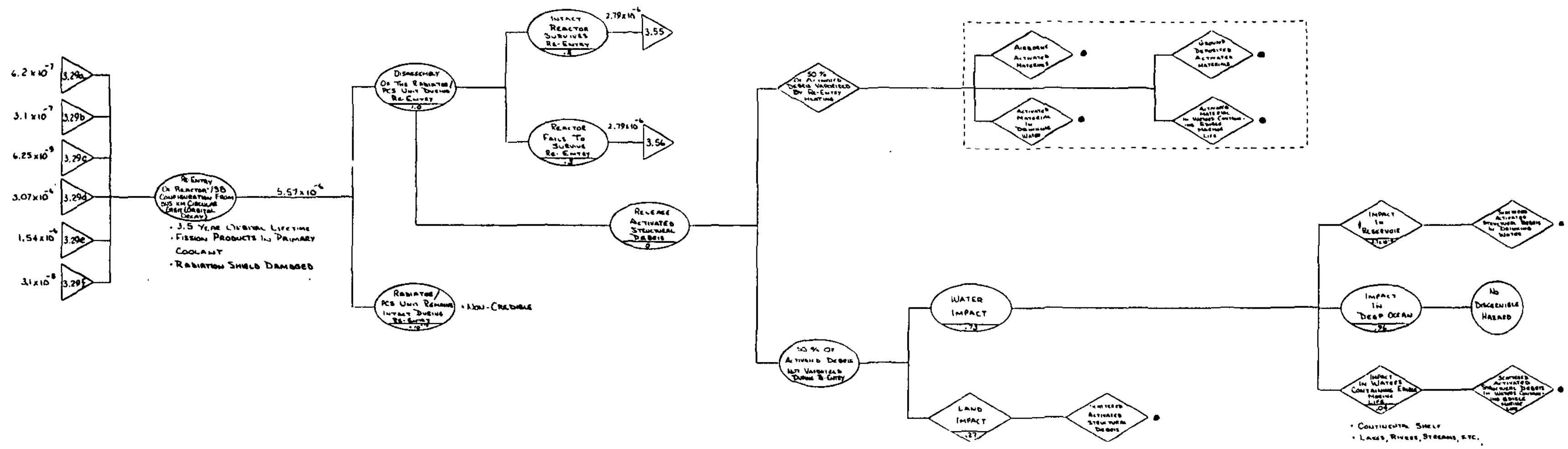


Figure D-26. Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay (Fuel Cladding & Primary NaK Loop Breached, Radiation Shield Damaged)

D-30 A

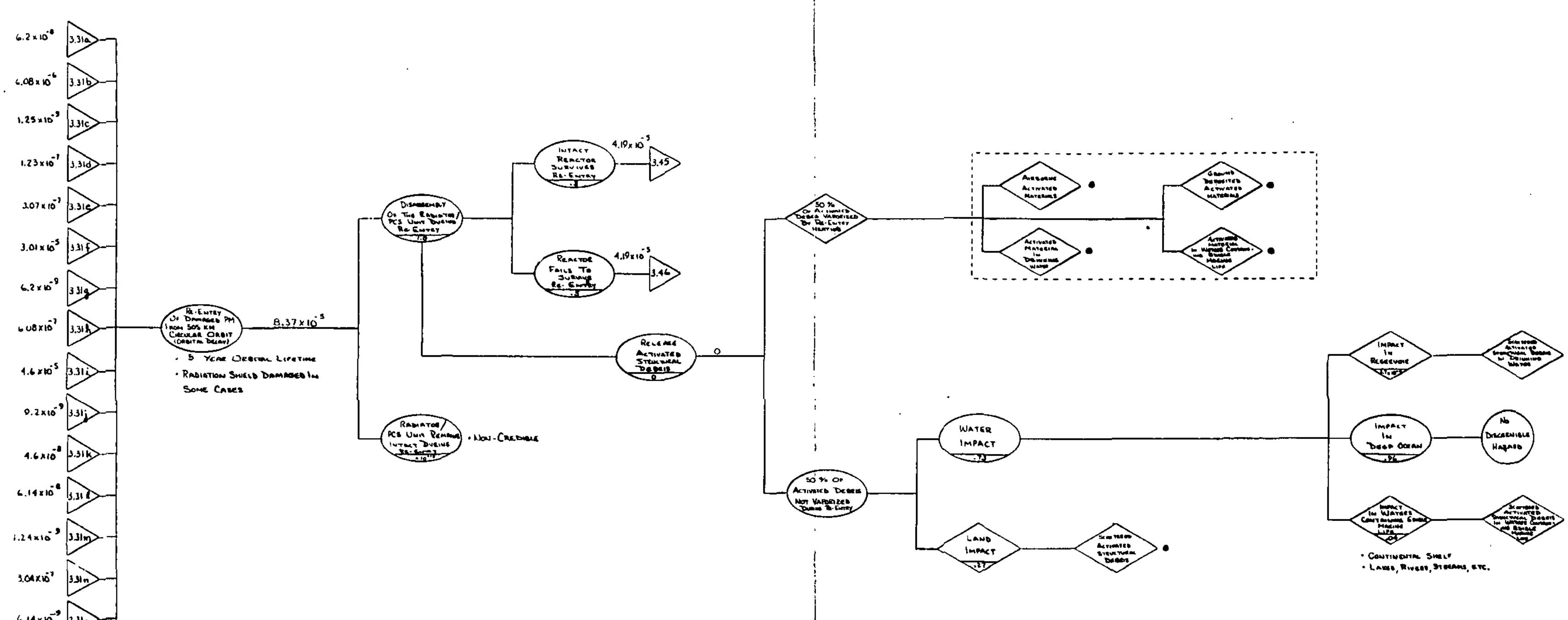
B



D-31 A

(B)

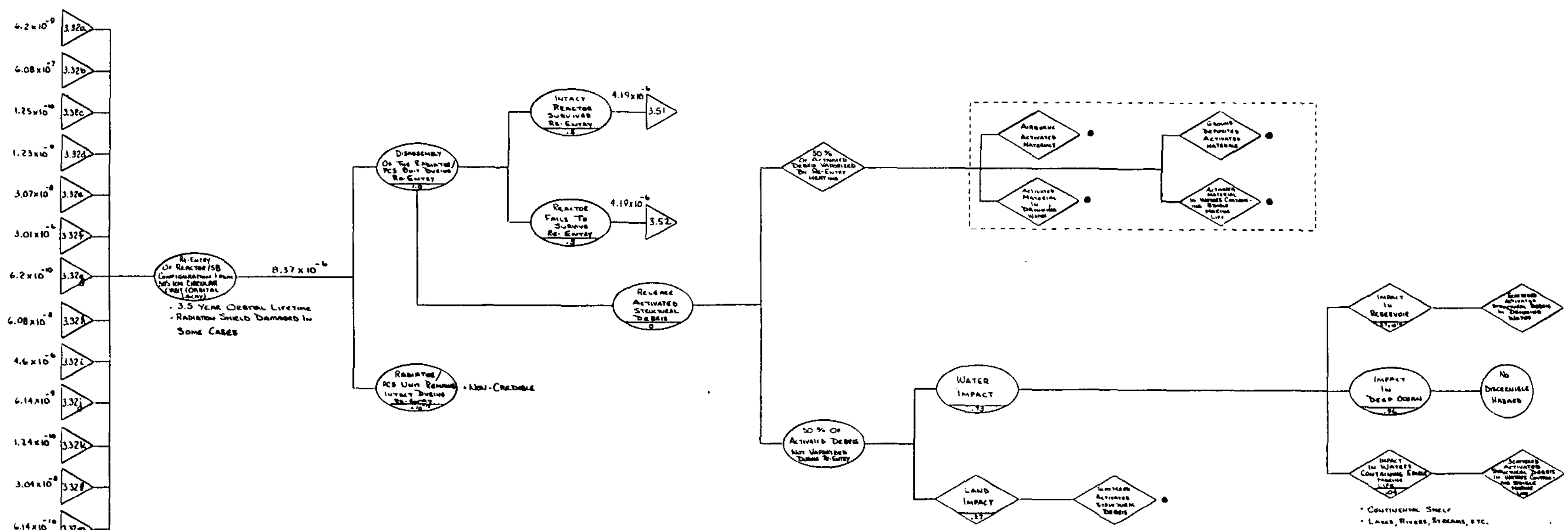
Figure D-27. Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay (Fission Products in Primary Coolant, Radiation Shield Damaged)



D-32 A

Figure D-28. Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay (Radiation Shield Damaged in Some Cases)

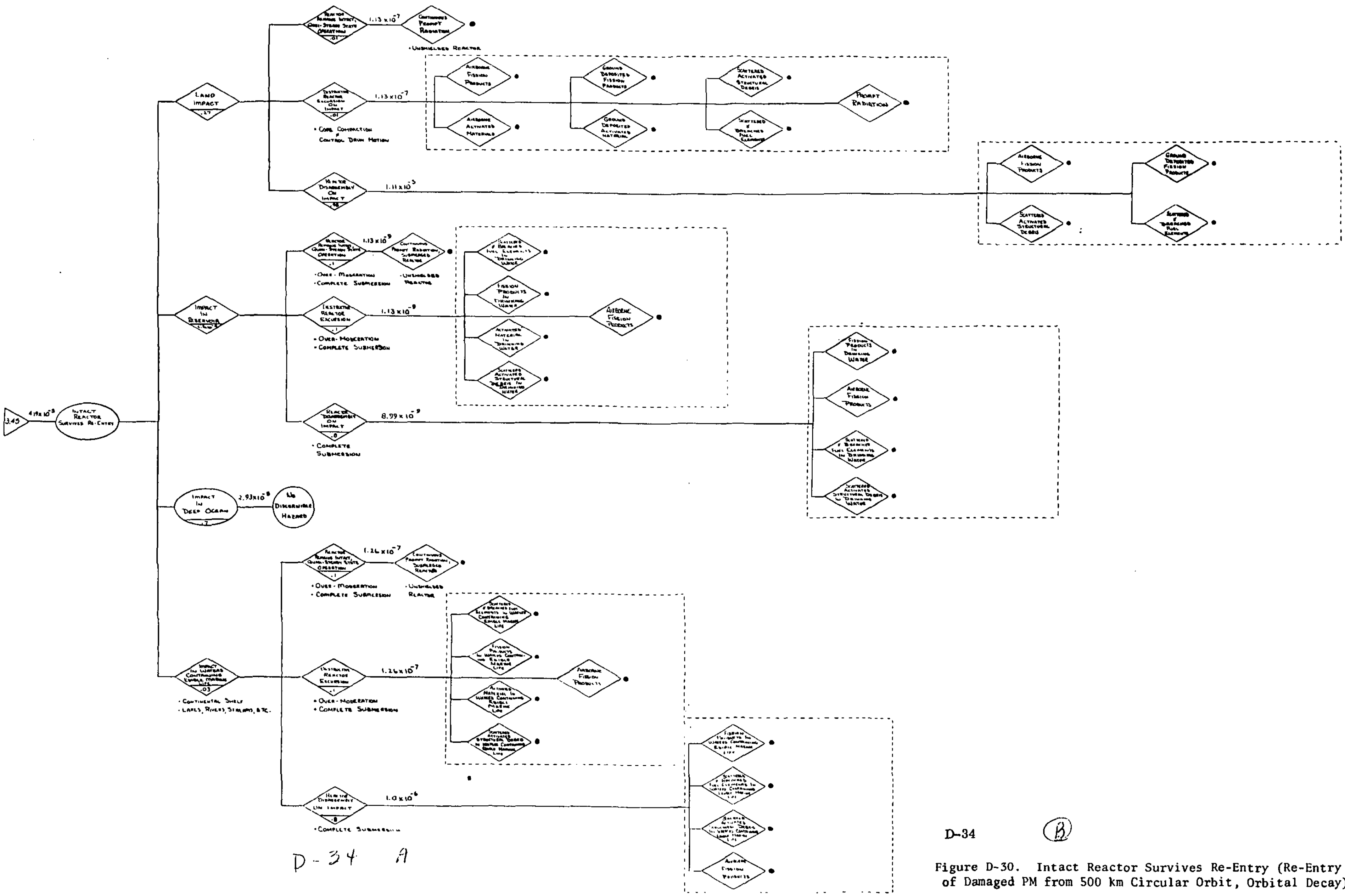
B



D - 33 A

Figure D-29. Re-Entry of Reactor/SB Configuration from 500 km Circular Orbit, Orbital Decay (Radiation Shield Damaged in Some Cases)

B



D-34 (B)

Figure D-30. Intact Reactor Survives Re-Entry (Re-Entry of Damaged PM from 500 km Circular Orbit, Orbital Decay)

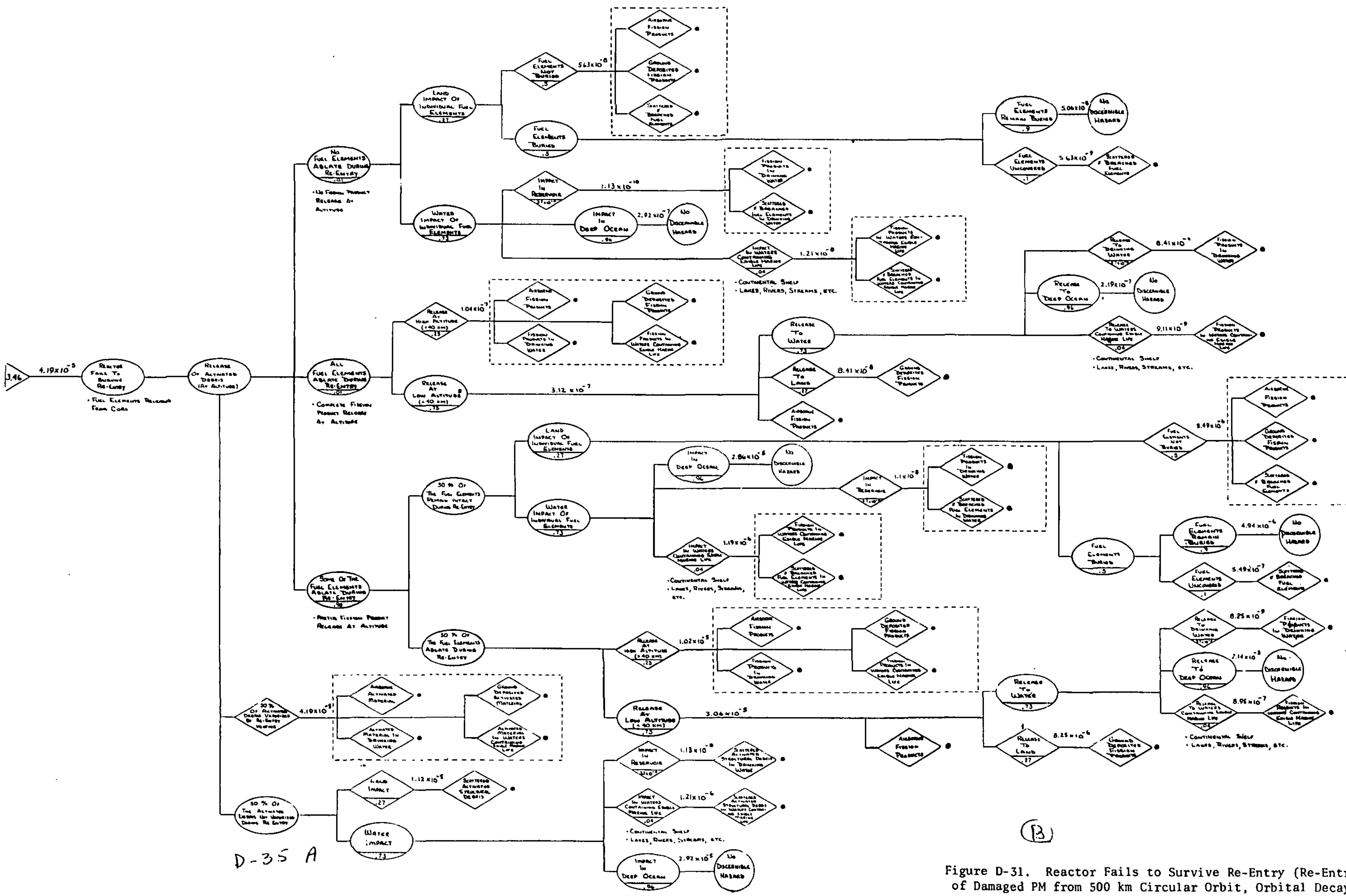


Figure D-31. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged PM from 500 km Circular Orbit, Orbital Decay)

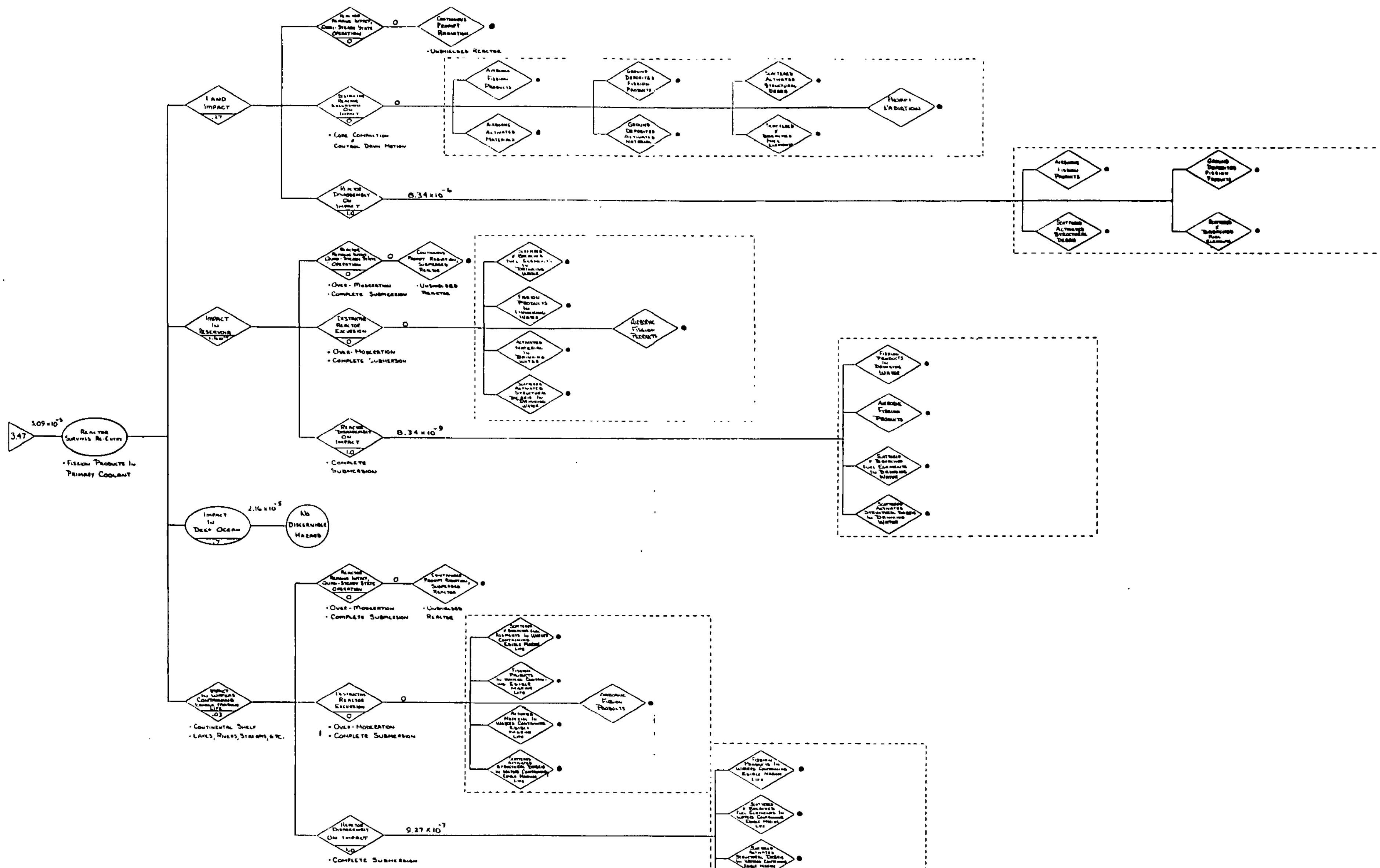
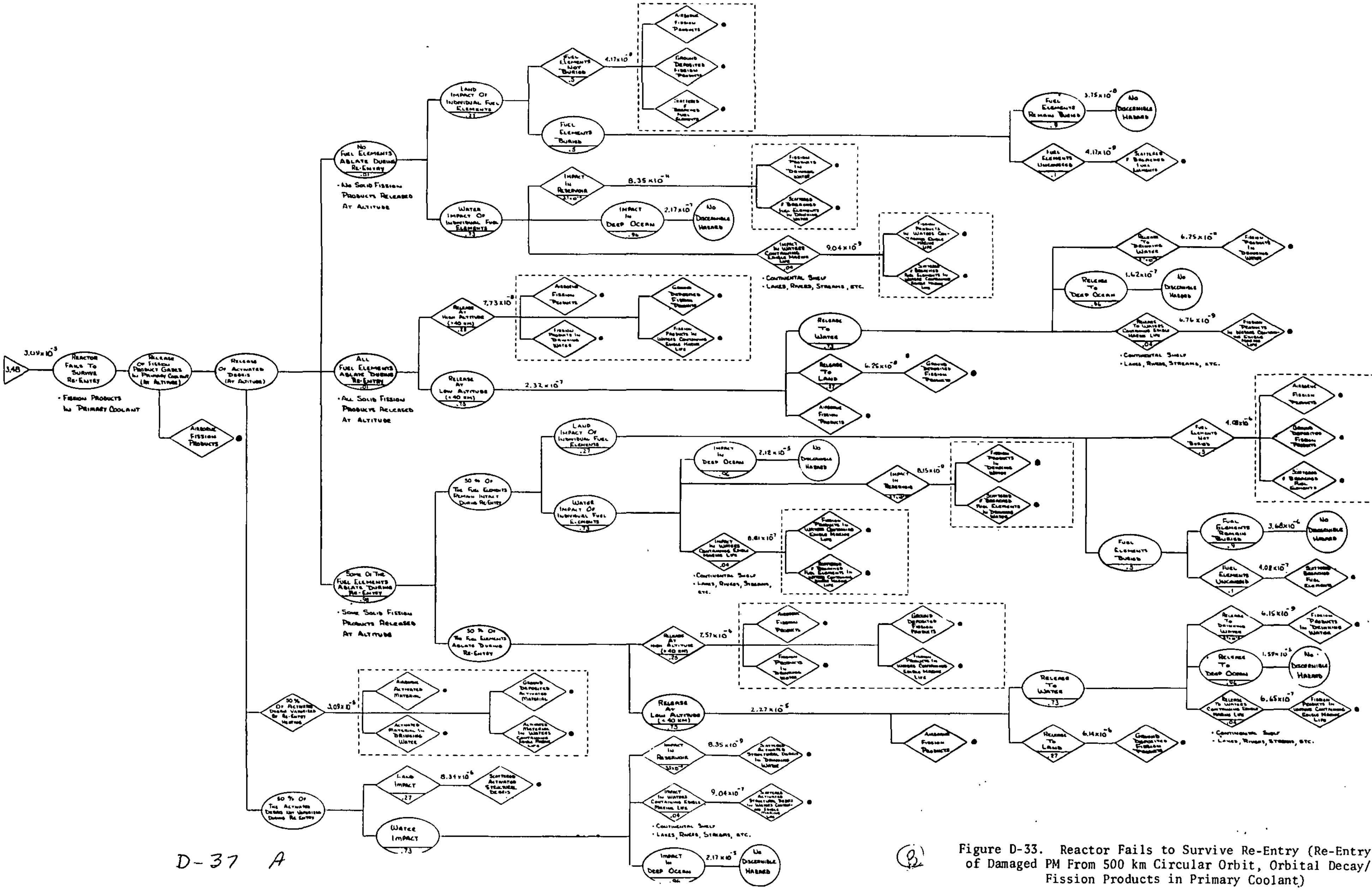
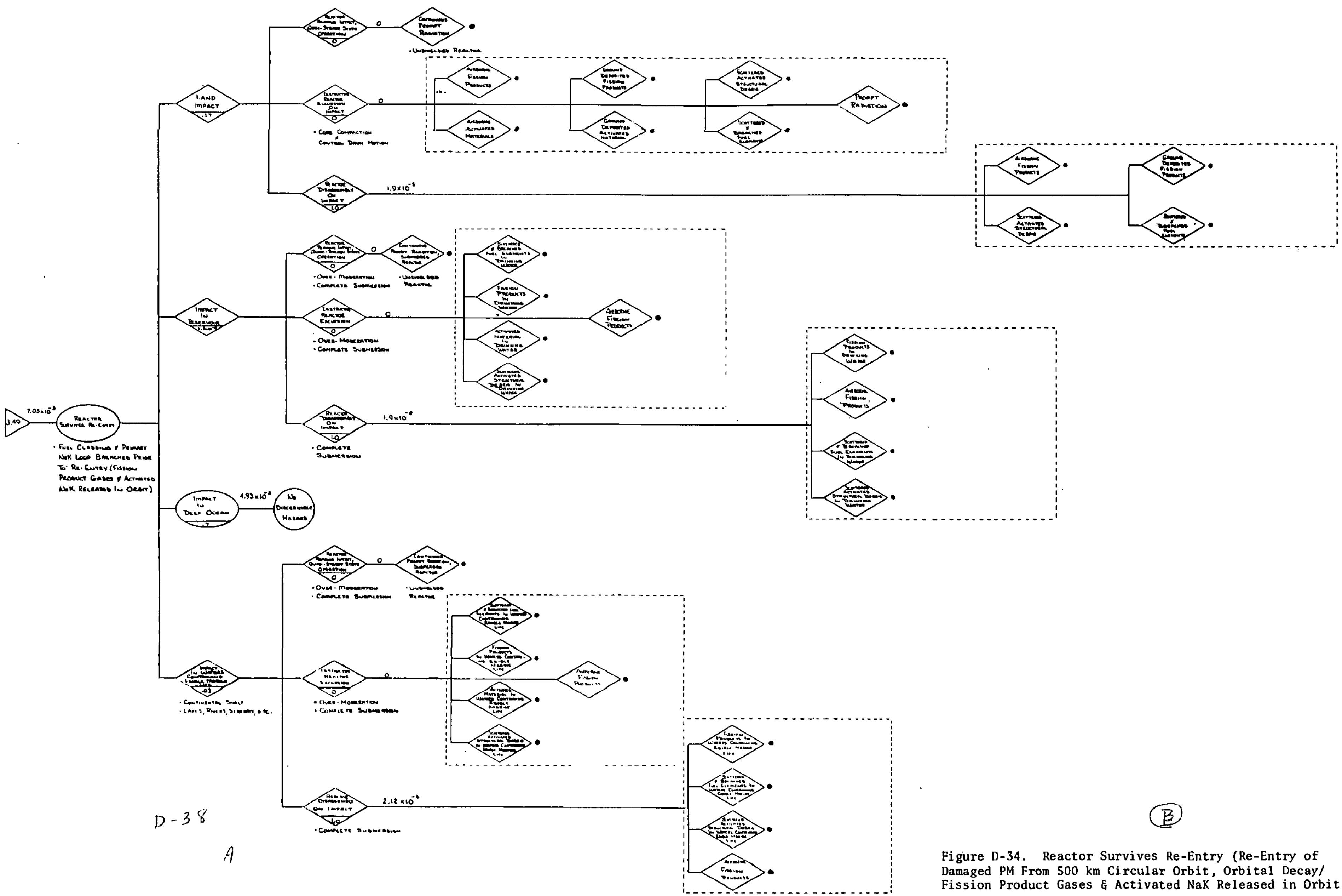


Figure D-32. Reactor Survives Re-Entry (Re-Entry of Damaged PM from 500 km Circular Orbit, Orbital Decay/ Fission Products in Primary Coolant)



D-37 A

Figure D-33. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay/ Fission Products in Primary Coolant)



D-38

A

B

Figure D-34. Reactor Survives Re-Entry (Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay/ Fission Product Gases & Activated NaK Released in Orbit.

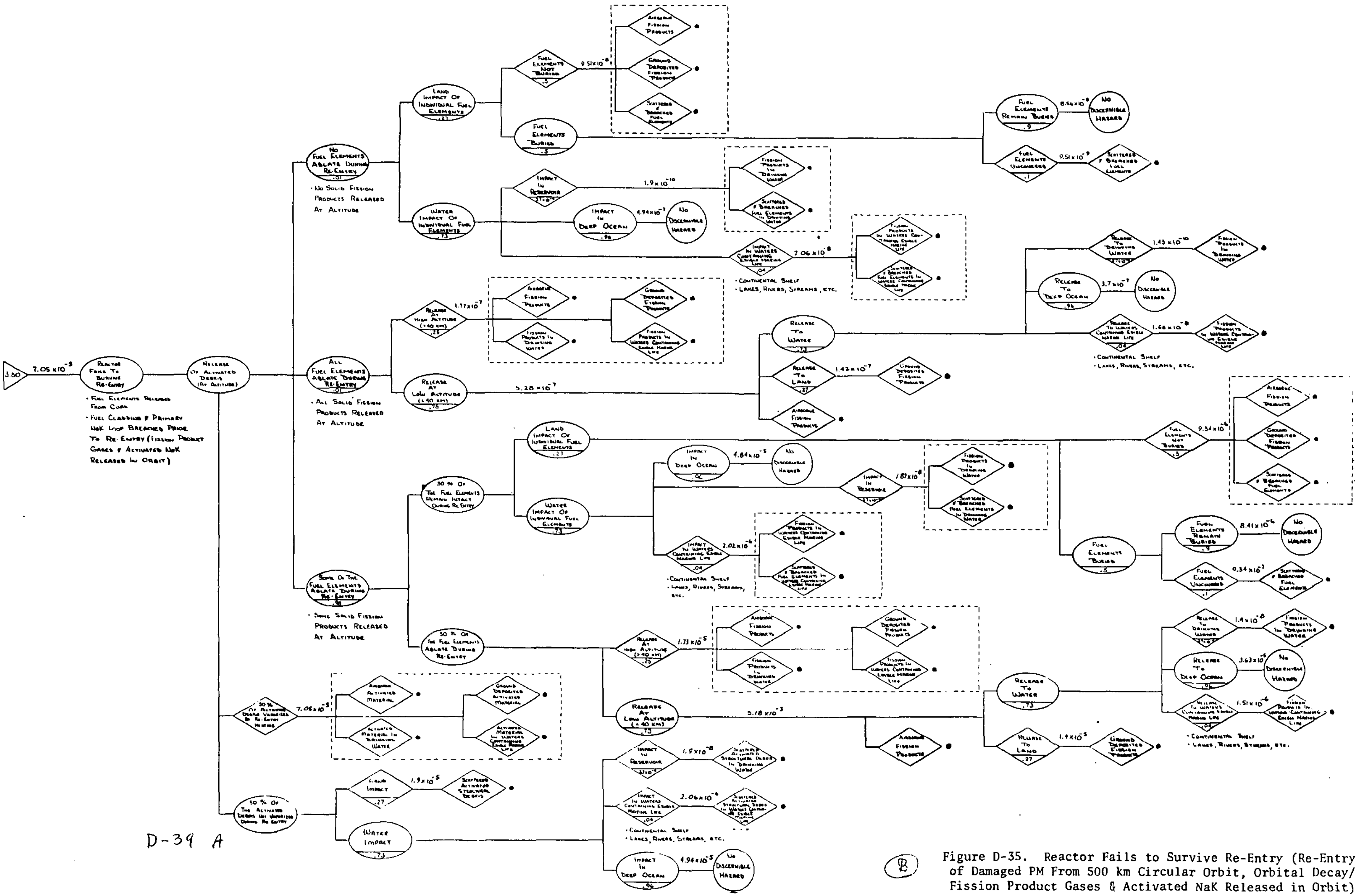


Figure D-35. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay/ Fission Product Gases & Activated NaK Released in Orbit)

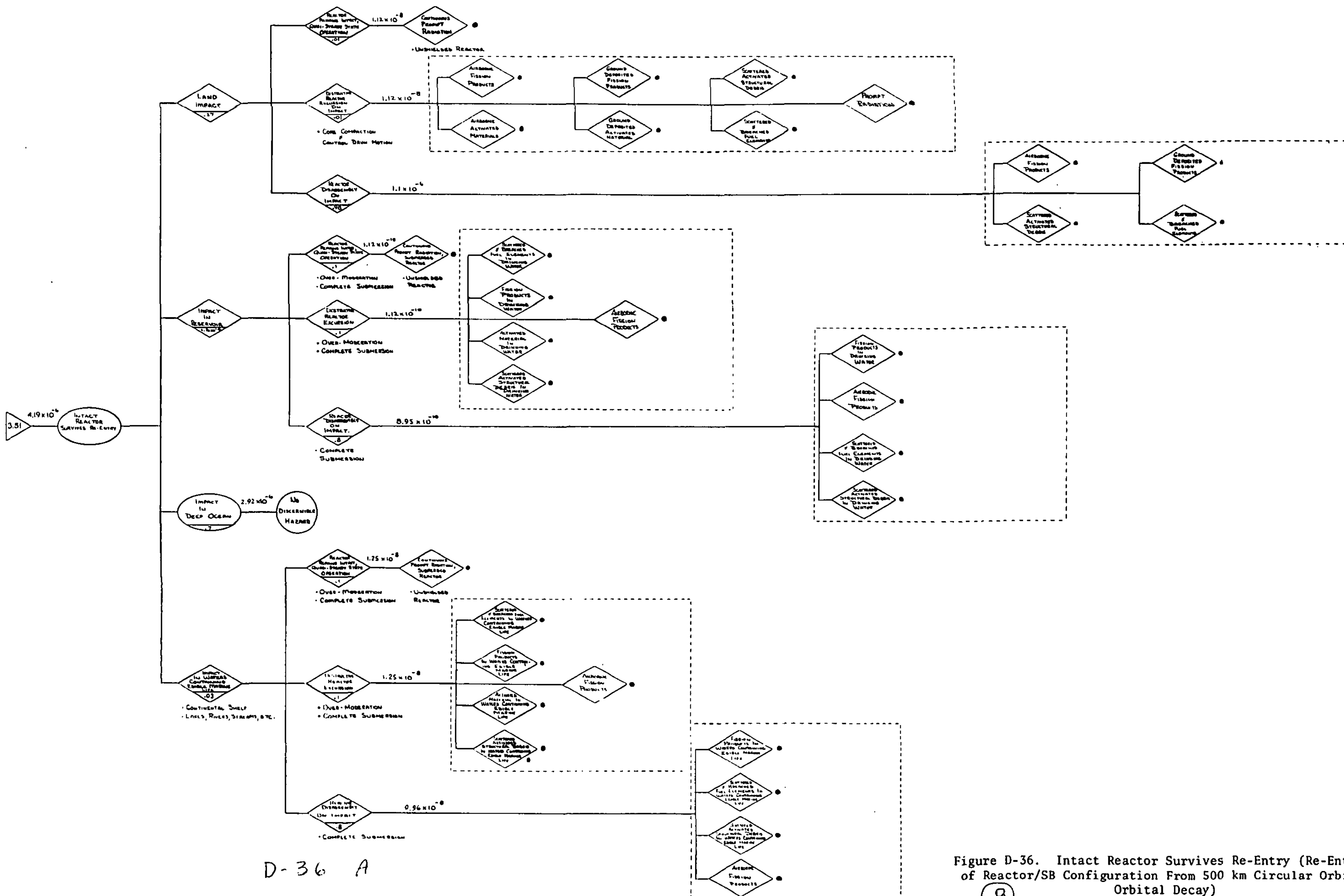


Figure D-36. Intact Reactor Survives Re-Entry (Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay)

B

D-41 A

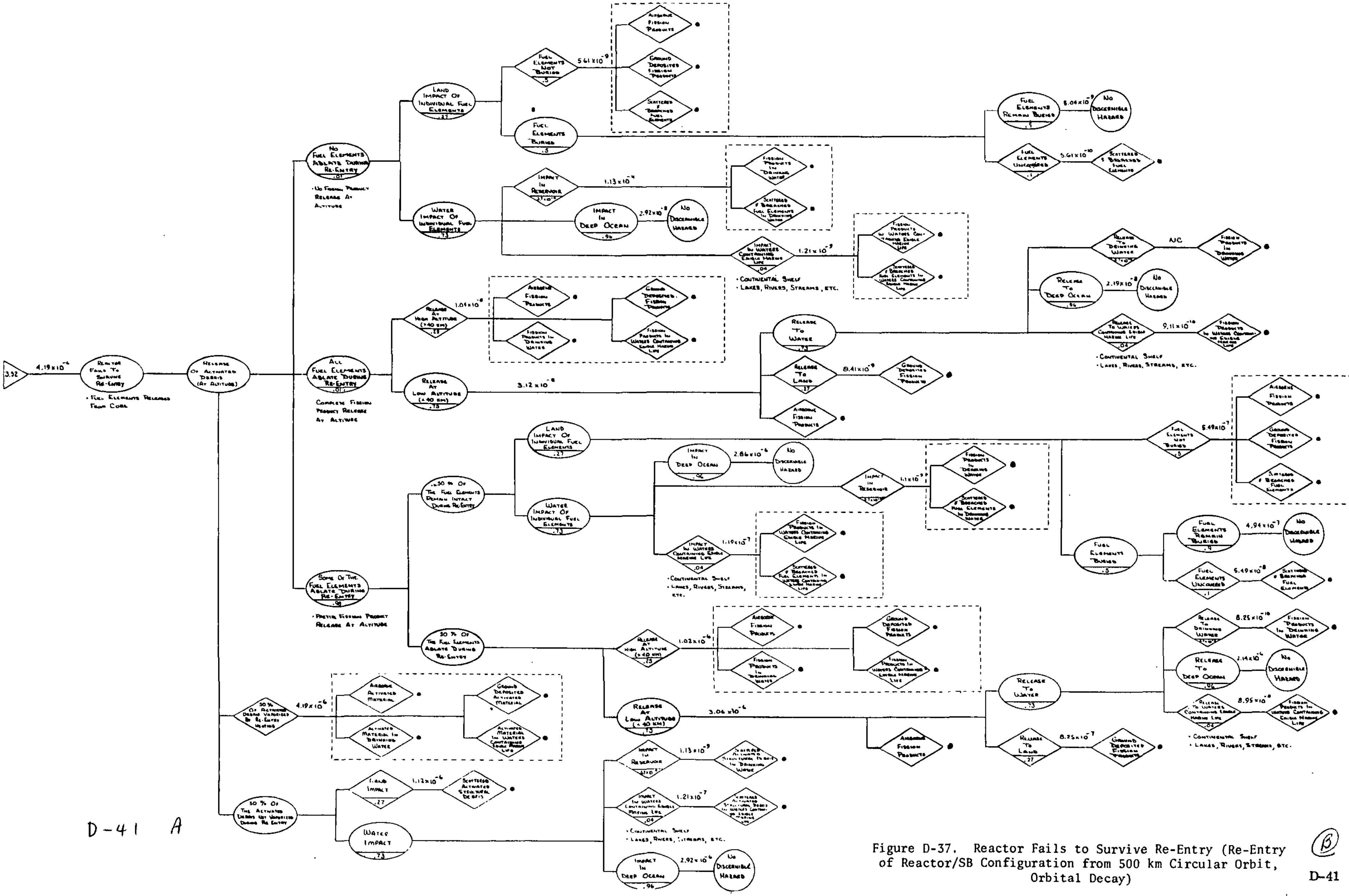


Figure D-37. Reactor Fails to Survive Re-Entry (Re-Entry of Reactor/SB Configuration from 500 km Circular Orbit, Orbital Decay)

(B)

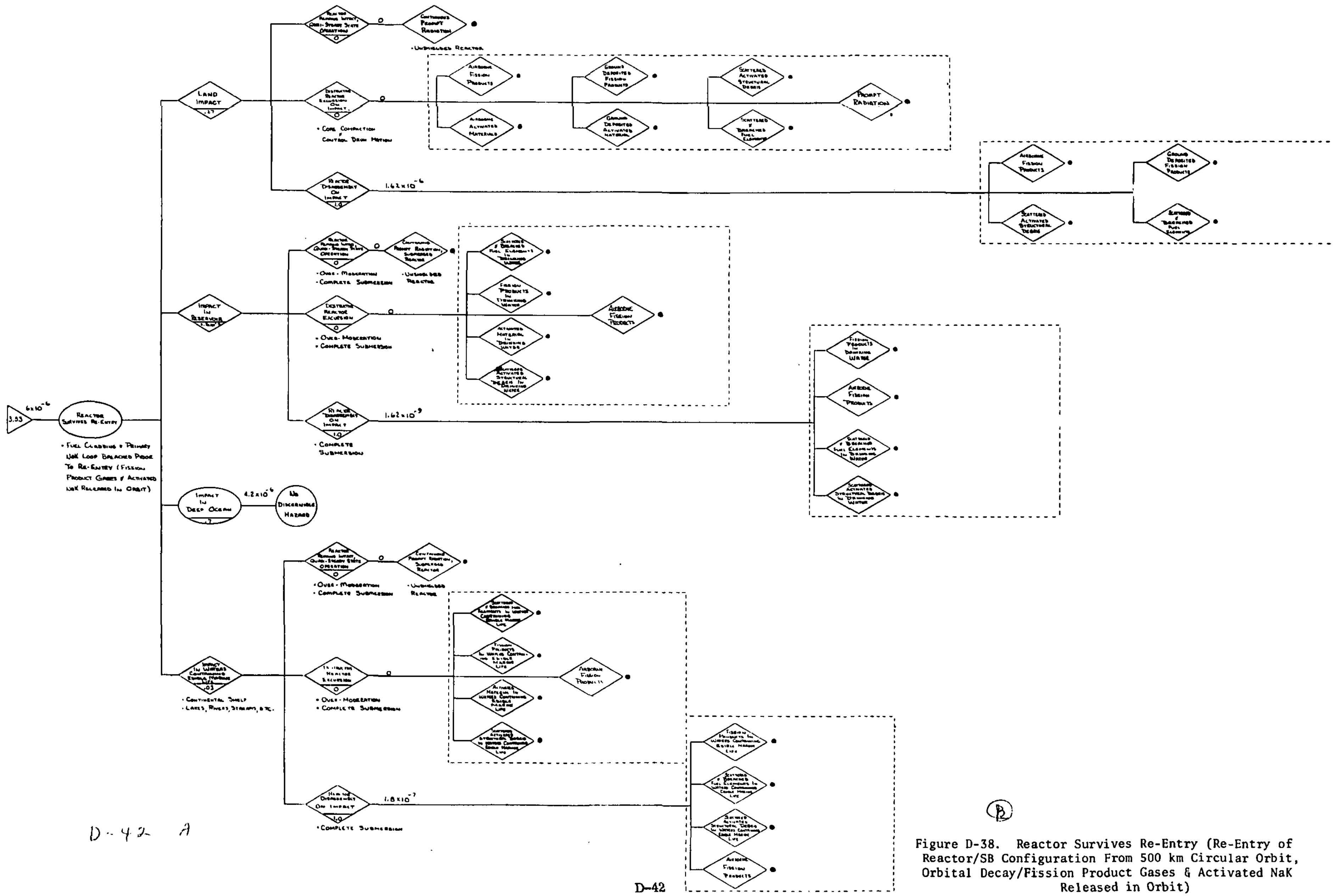
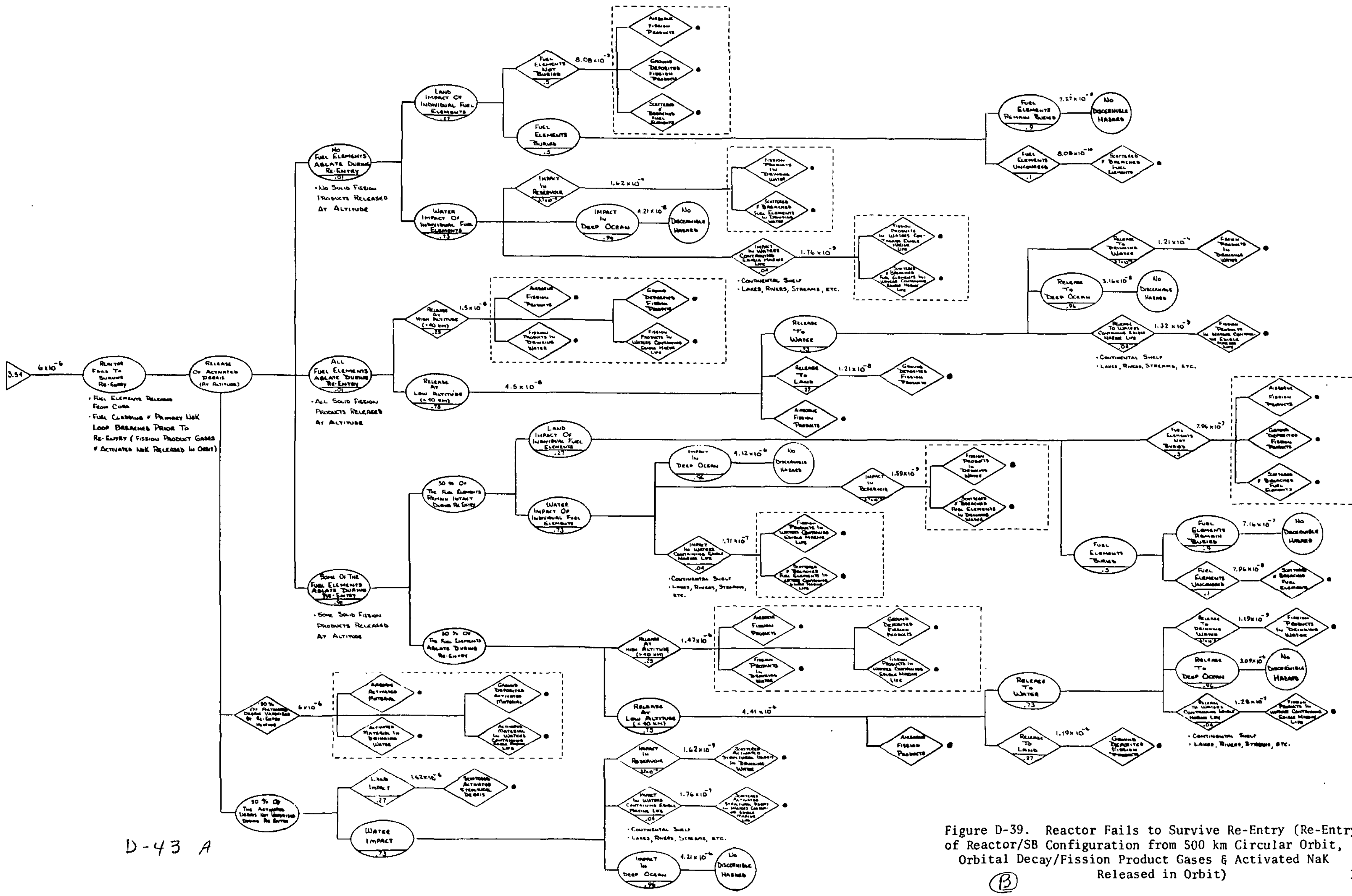


Figure D-38. Reactor Survives Re-Entry (Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay/Fission Product Gases & Activated NaK Released in Orbit)



D-43 A

Figure D-39. Reactor Fails to Survive Re-Entry (Re-Entry of Reactor/SB Configuration from 500 km Circular Orbit, Orbital Decay/Fission Product Gases & Activated NaK Released in Orbit)

B

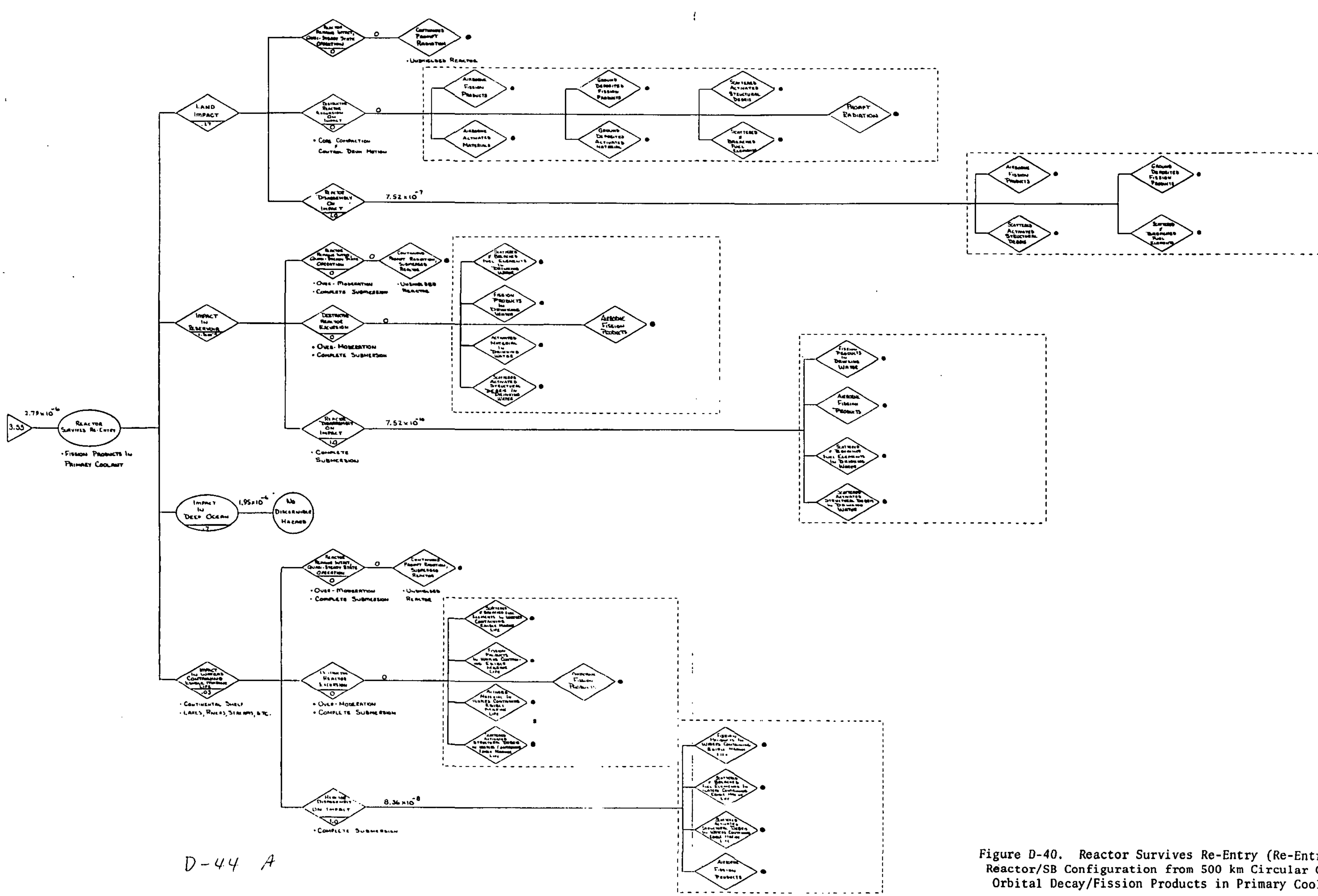


Figure D-40. Reactor Survives Re-Entry (Re-Entry of Reactor/SB Configuration from 500 km Circular Orbit, Orbital Decay/Fission Products in Primary Coolant)

B

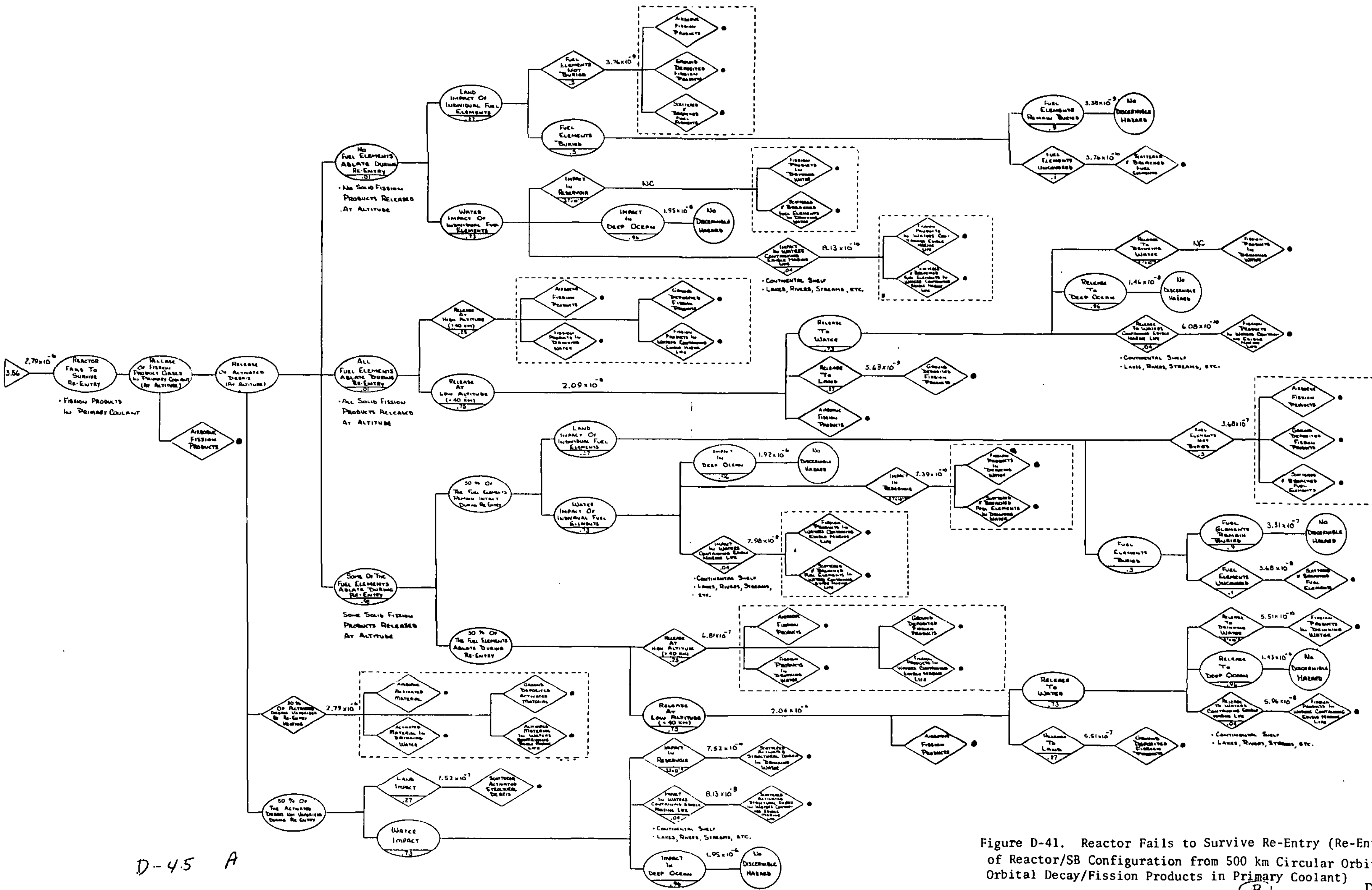


Figure D-41. Reactor Fails to Survive Re-Entry (Re-Entry of Reactor/SB Configuration from 500 km Circular Orbit, Orbital Decay/Fission Products in Primary Coolant)

B

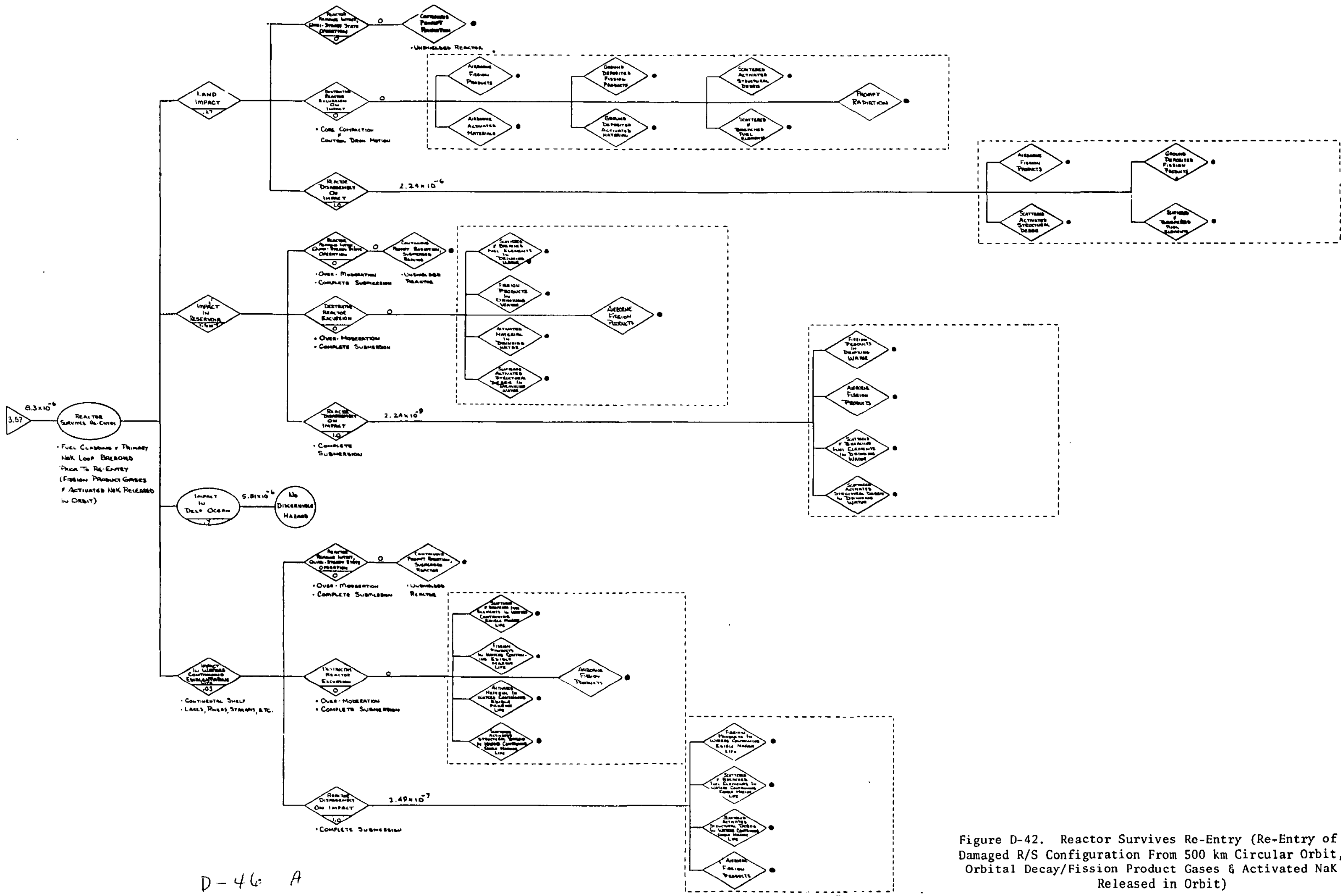
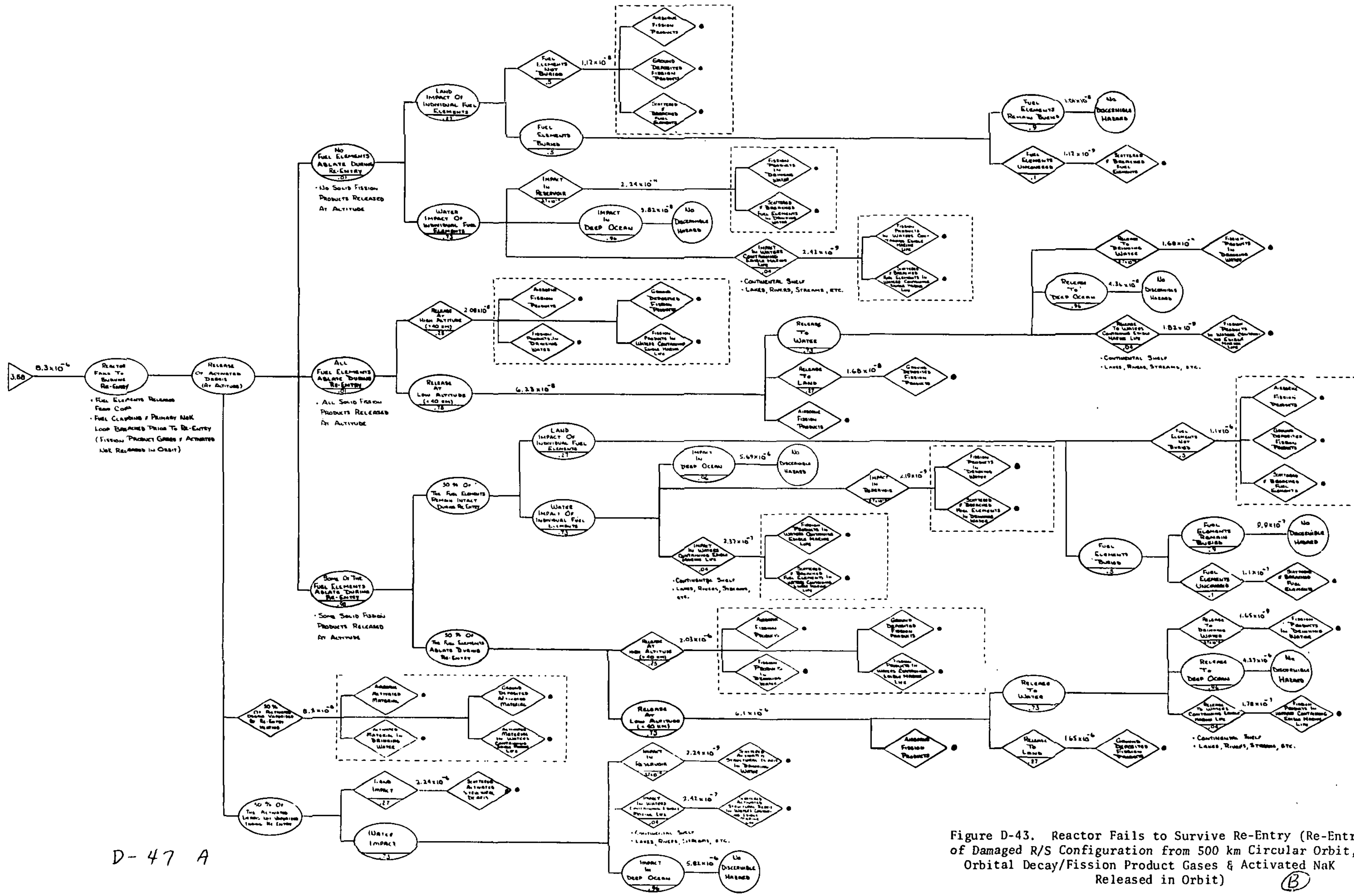


Figure D-42. Reactor Survives Re-Entry (Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay/Fission Product Gases & Activated NaK Released in Orbit)

D-46 A

13



D- 47 A

Figure D-43. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged R/S Configuration from 500 km Circular Orbit, Orbital Decay/Fission Product Gases & Activated NaK Released in Orbit) (B)

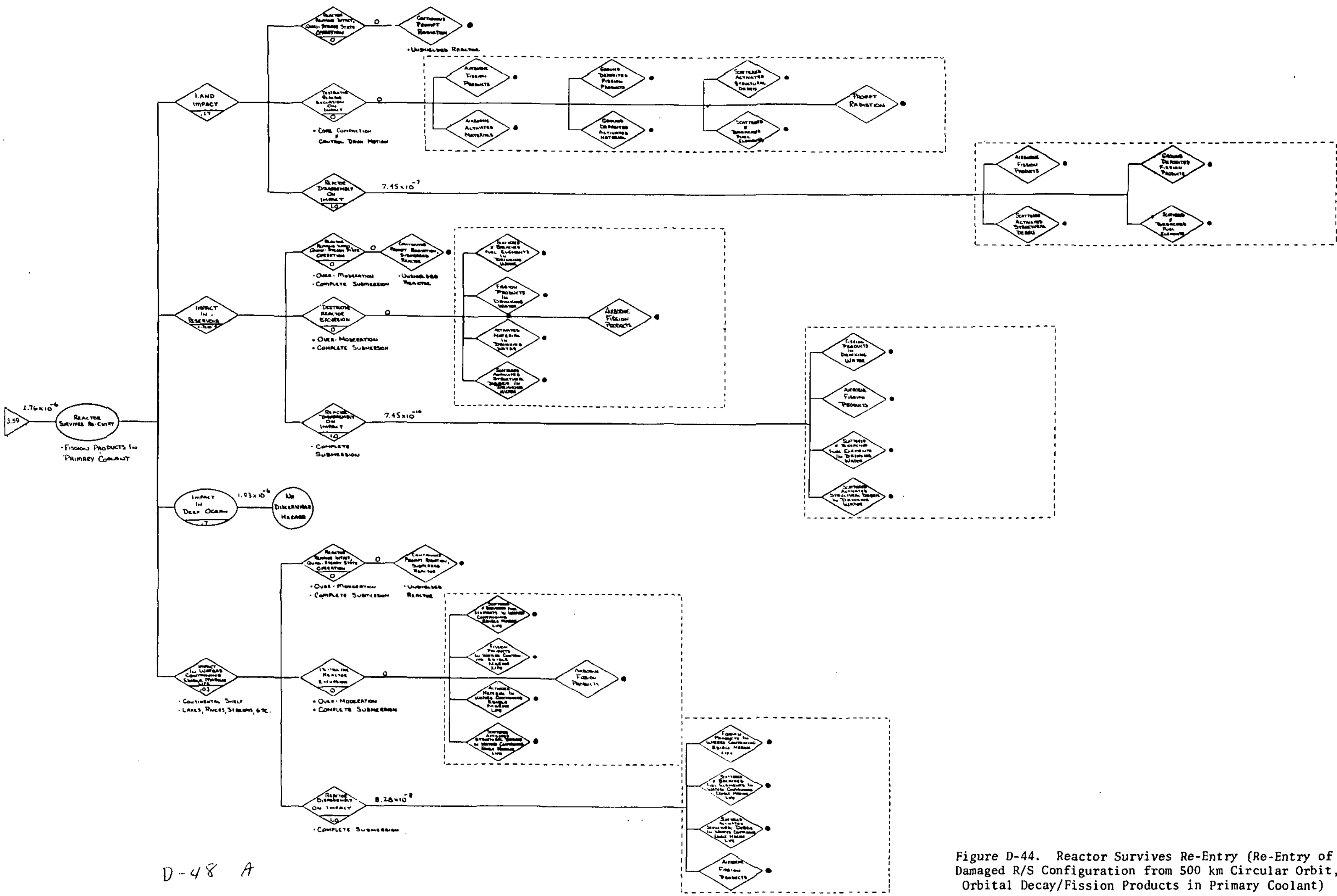


Figure D-44. Reactor Survives Re-Entry (Re-Entry of Damaged R/S Configuration from 500 km Circular Orbit, Orbital Decay/Fission Products in Primary Coolant)

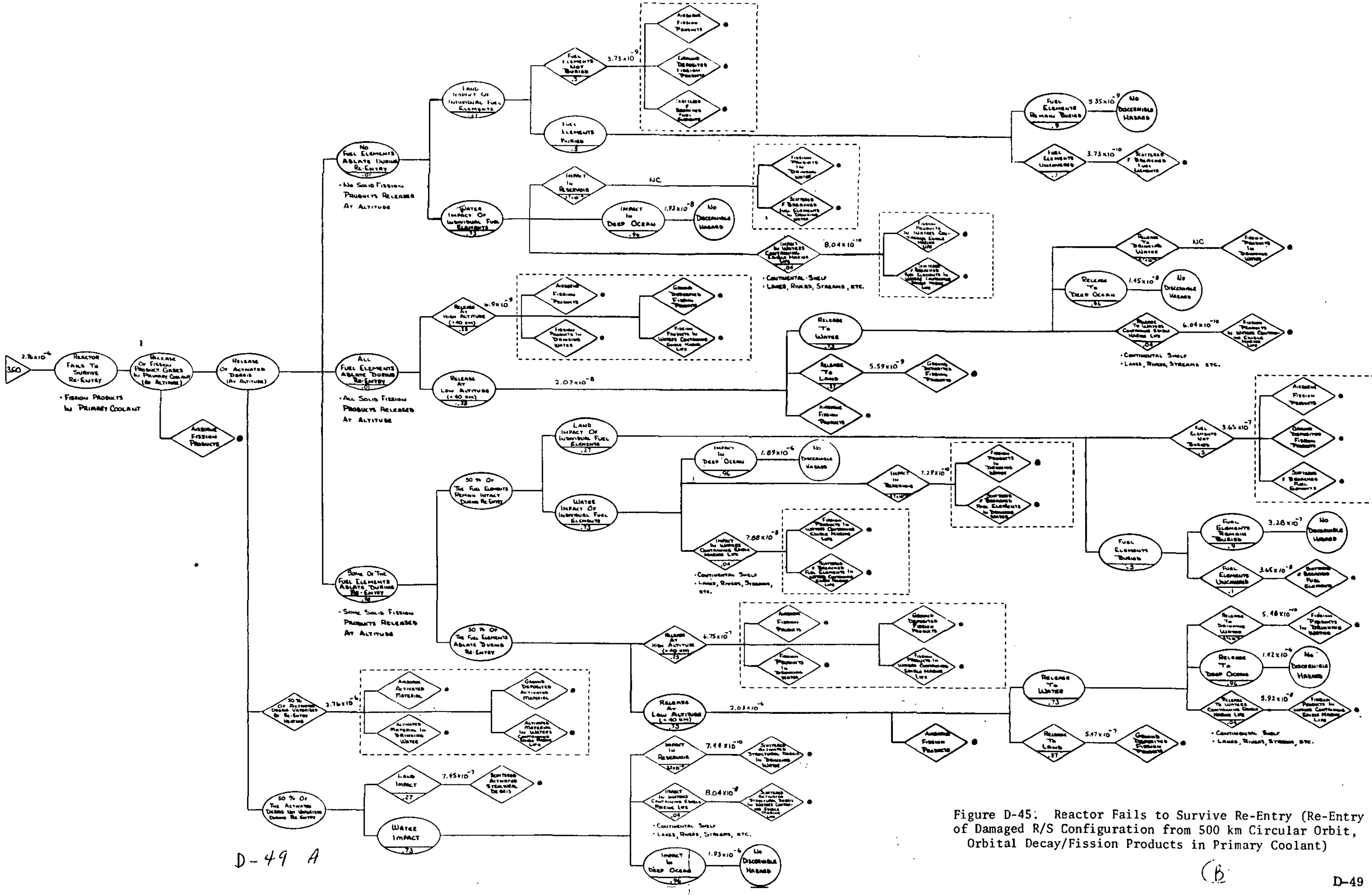
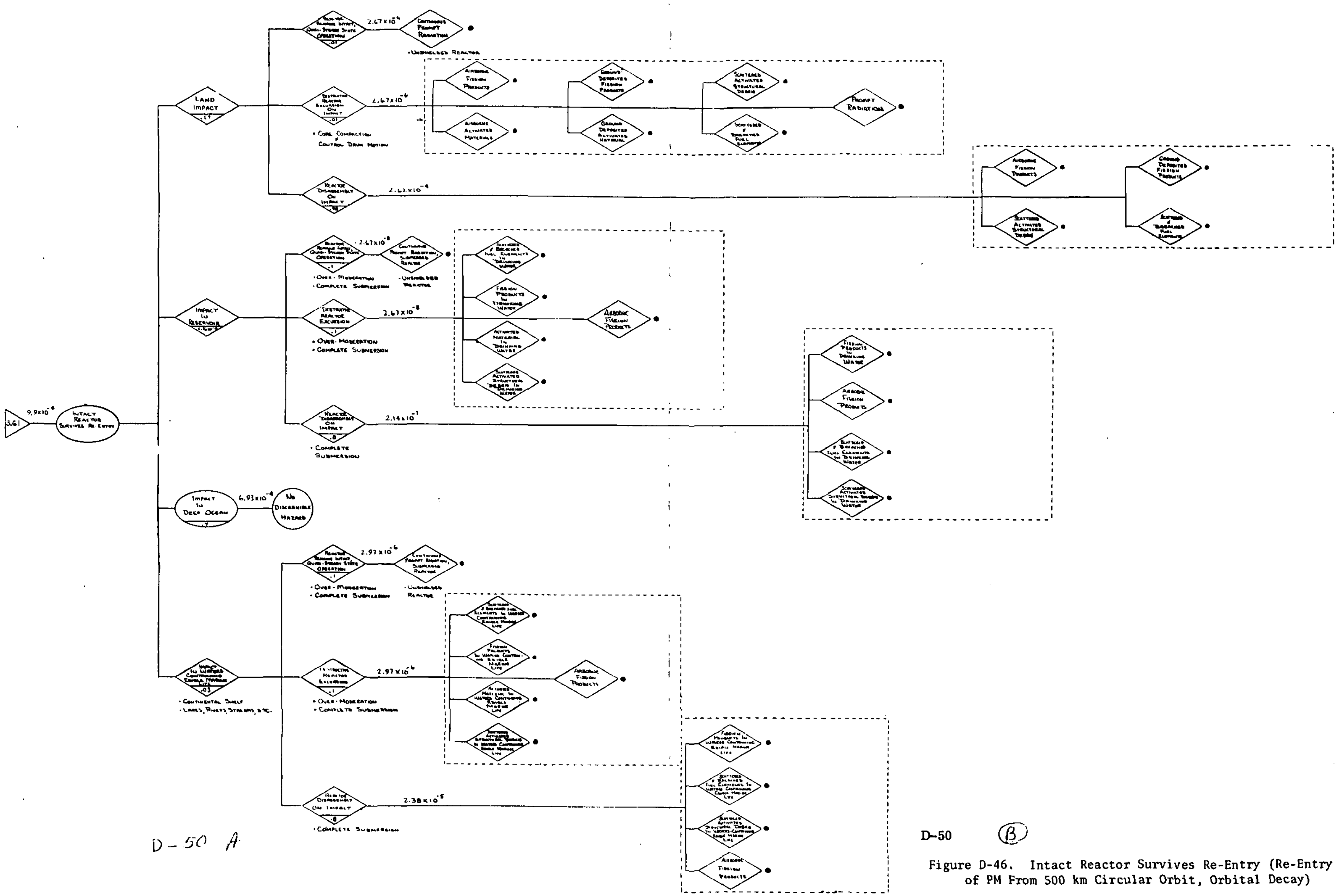


Figure D-45: Reactor Fails to Survive Re-Entry (Re-Entry of Damaged R/S Configuration from 500 km Circular Orbit, Orbital Decay/Fission Products in Primary Coolant)

D-49 A

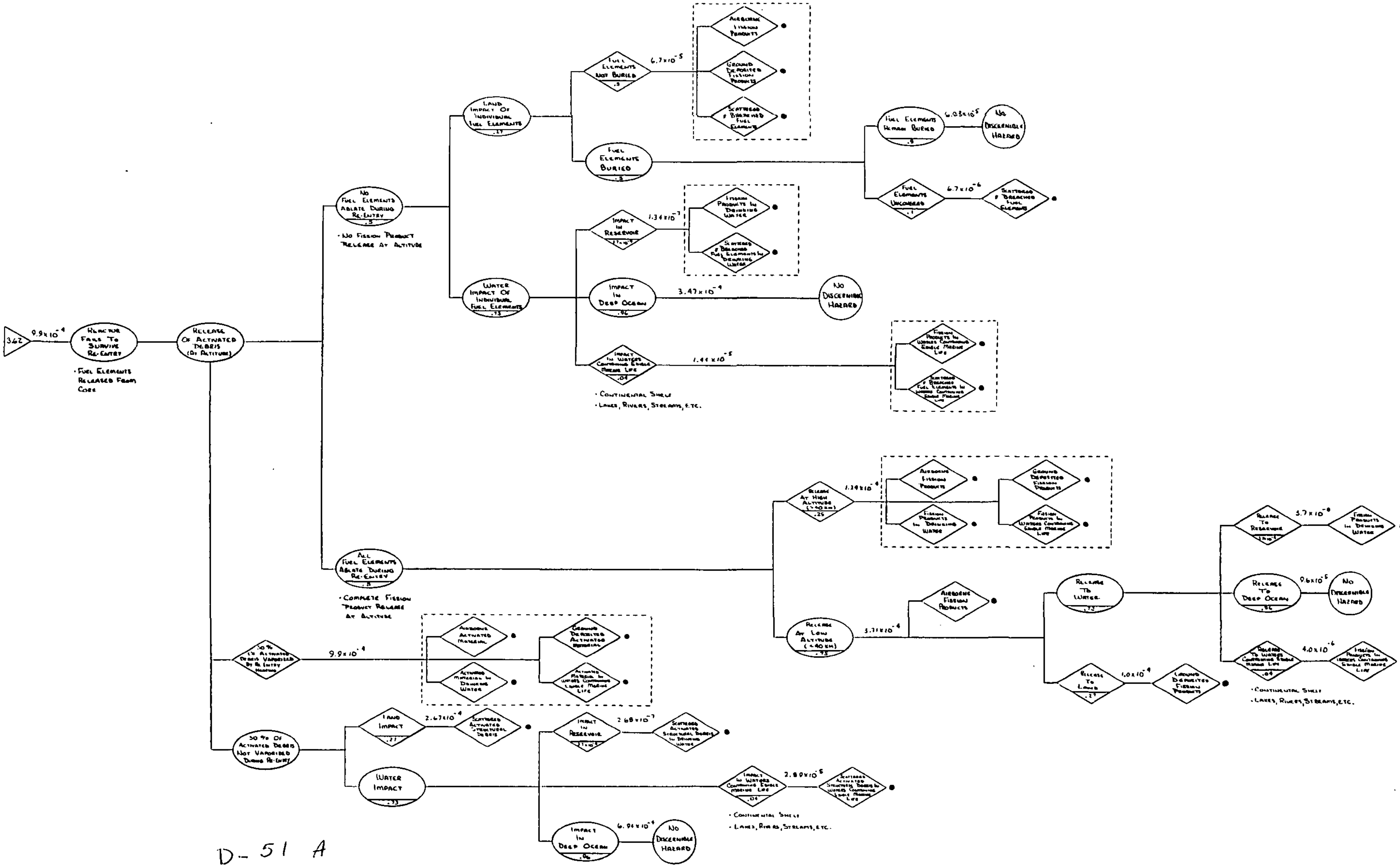
(B)



D-50 A

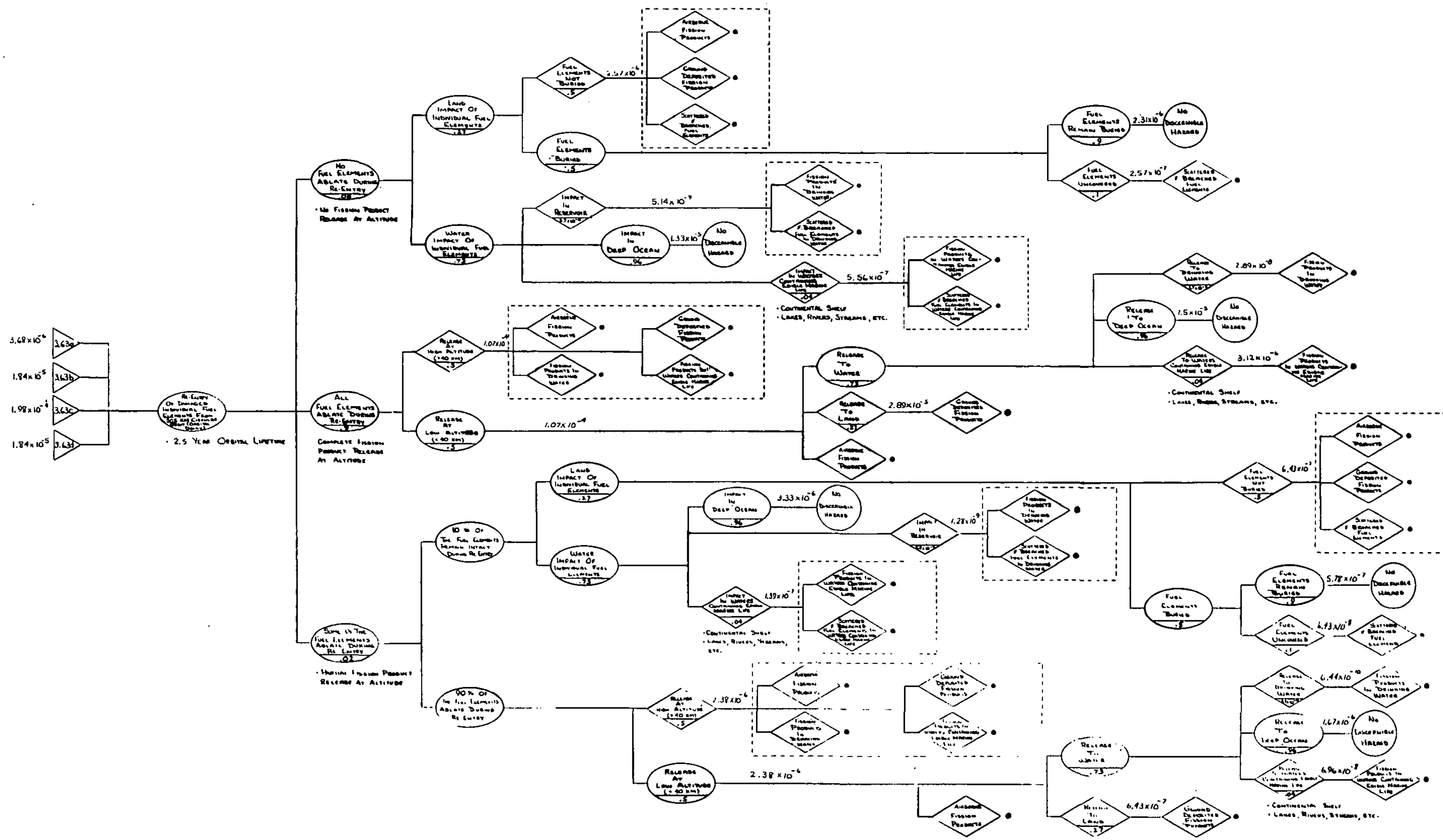
D-50 (B)

Figure D-46. Intact Reactor Survives Re-Entry (Re-Entry of PM From 500 km Circular Orbit, Orbital Decay)



D-51 A

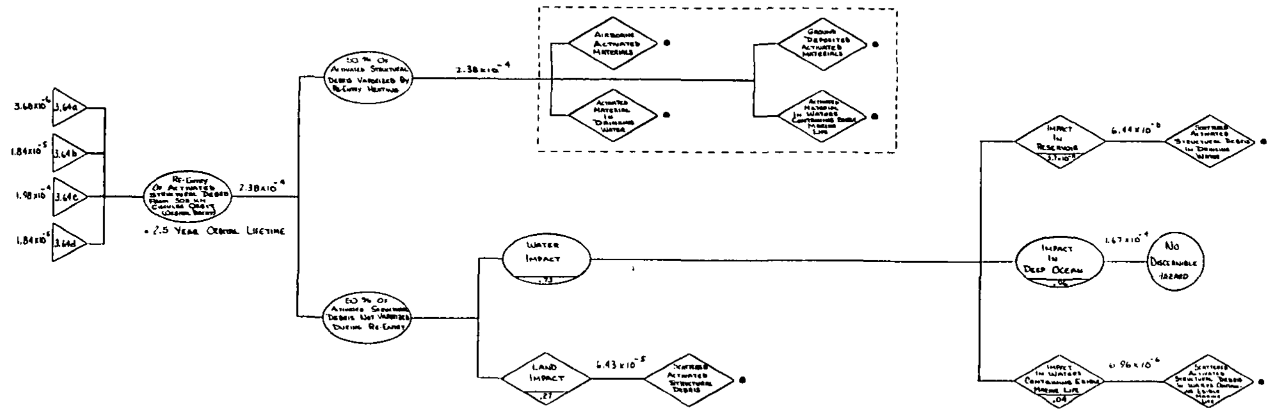
(B) Figure D-47. Reactor Fails to Survive Re-Entry (Re-Entry of PM from 500 km Circular Orbit, Orbital Decay)



D-52 A

Figure D-48. Re-Entry of Damaged Individual Fuel Elements From 500 km Circular Orbit (Orbital Decay)

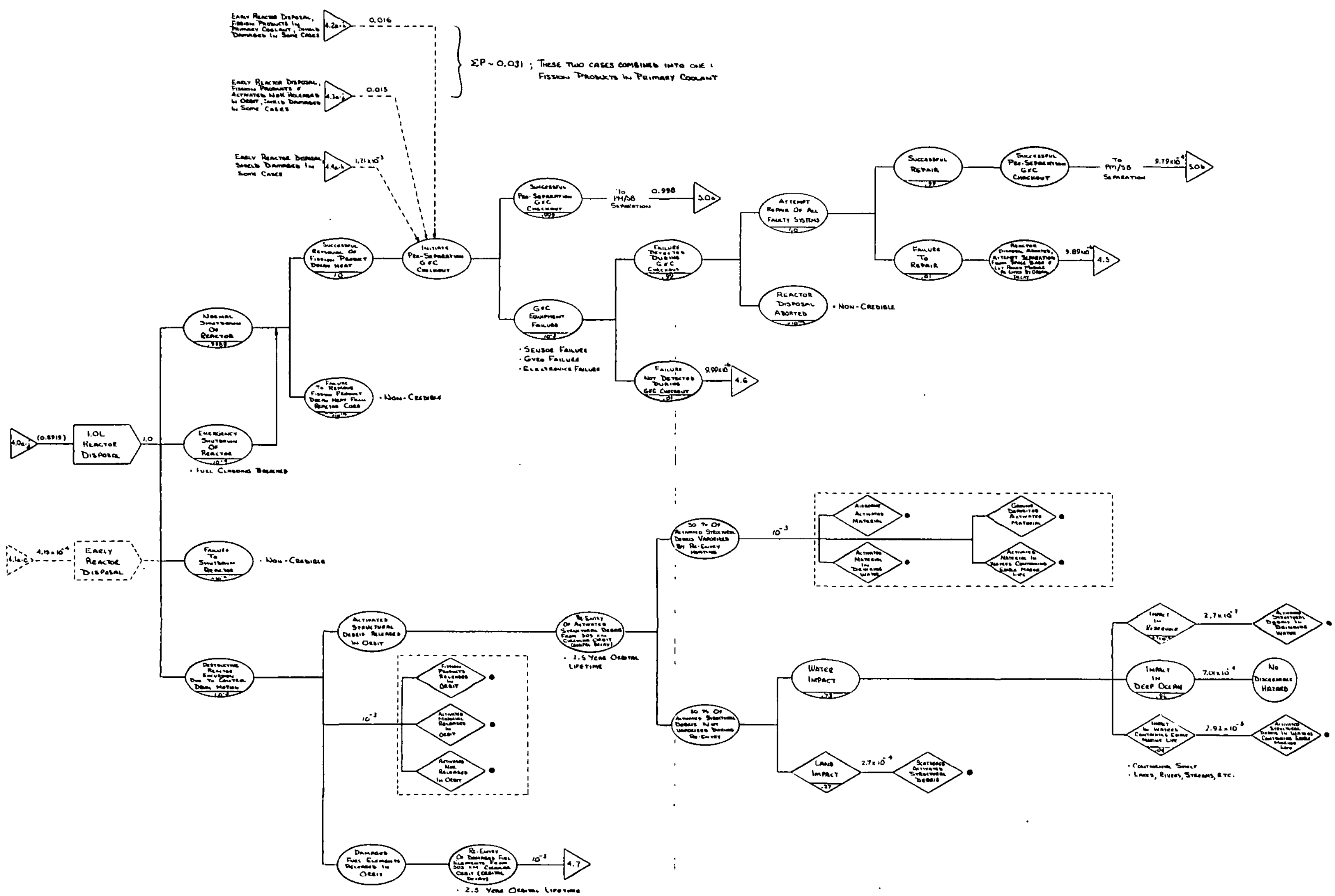
B



D-53 A

(B)

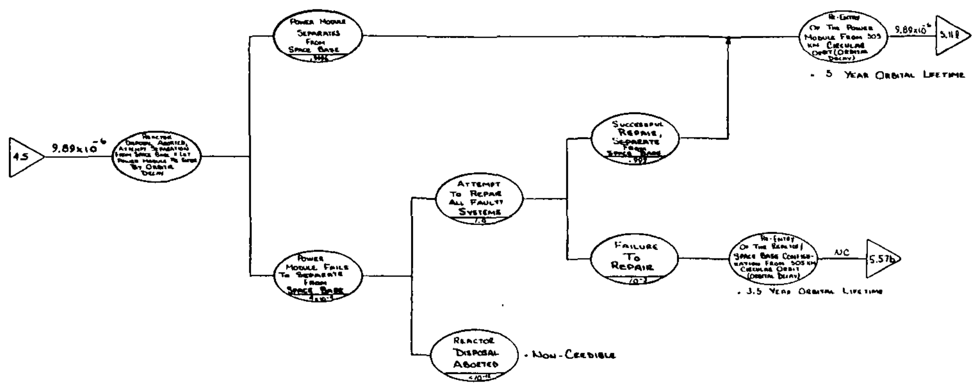
Figure D-49. Re-Entry of Activated Structural Debris From 500 km Circular Orbit (Orbital Decay)



D-54 A

D-54 (B)

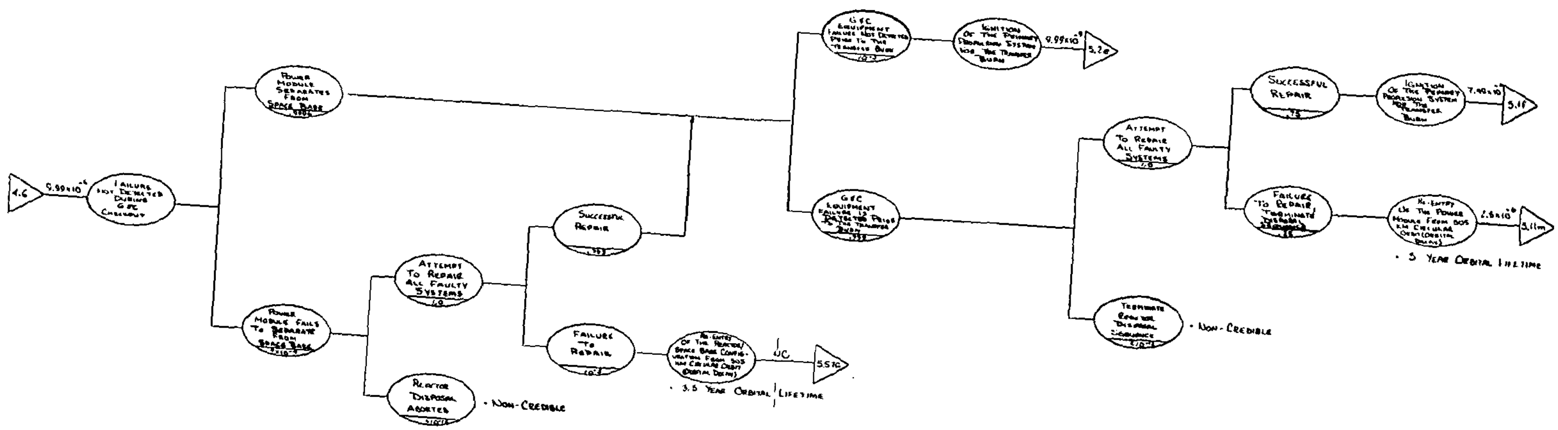
Figure D-50. Reactor Disposal



D-55 A

Figure D-51. Reactor Disposal Aborted, Attempt Separation From SB and Let PM Re-Enter By Orbital Decay

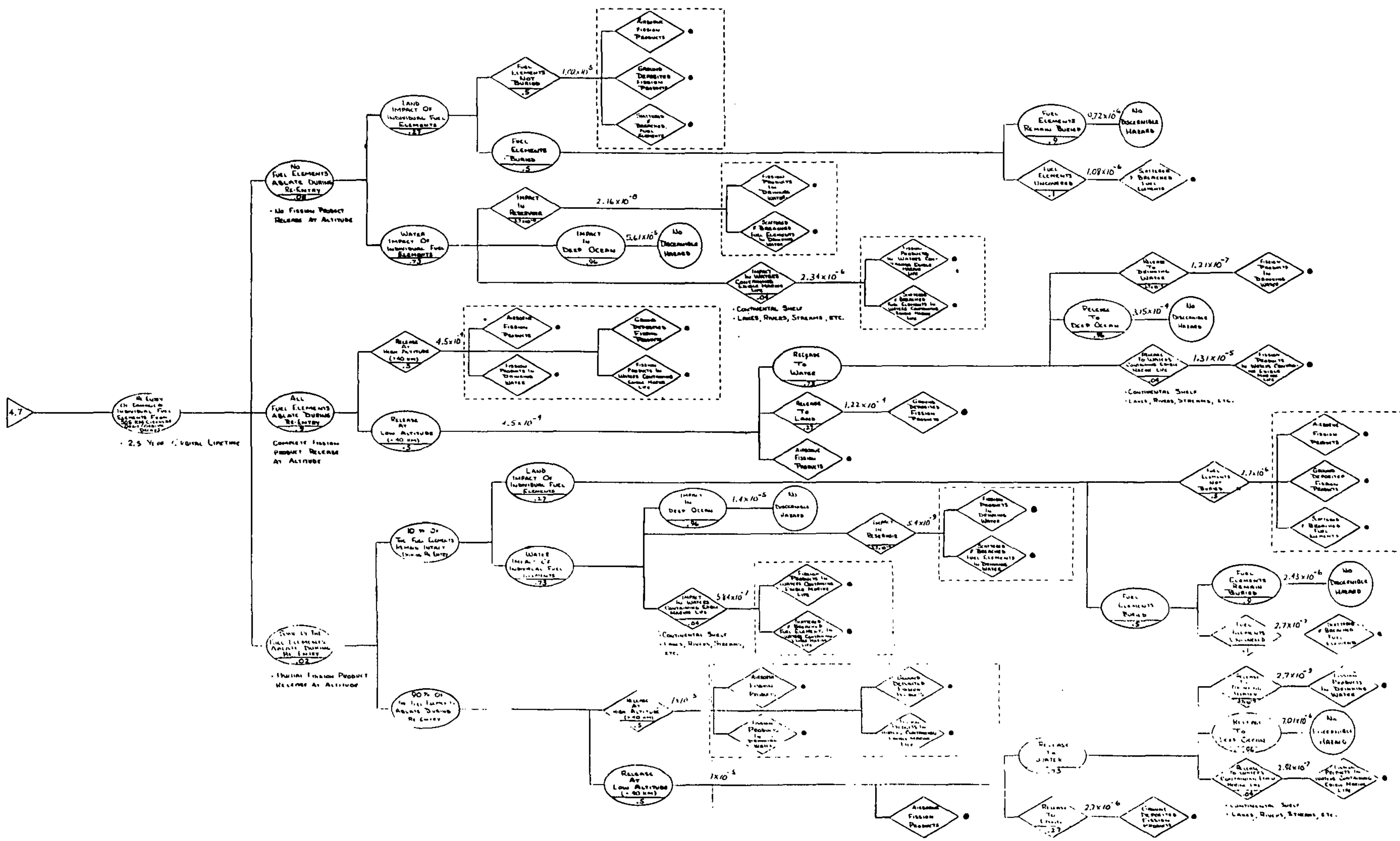
B



D-56 A

D-56 (B)

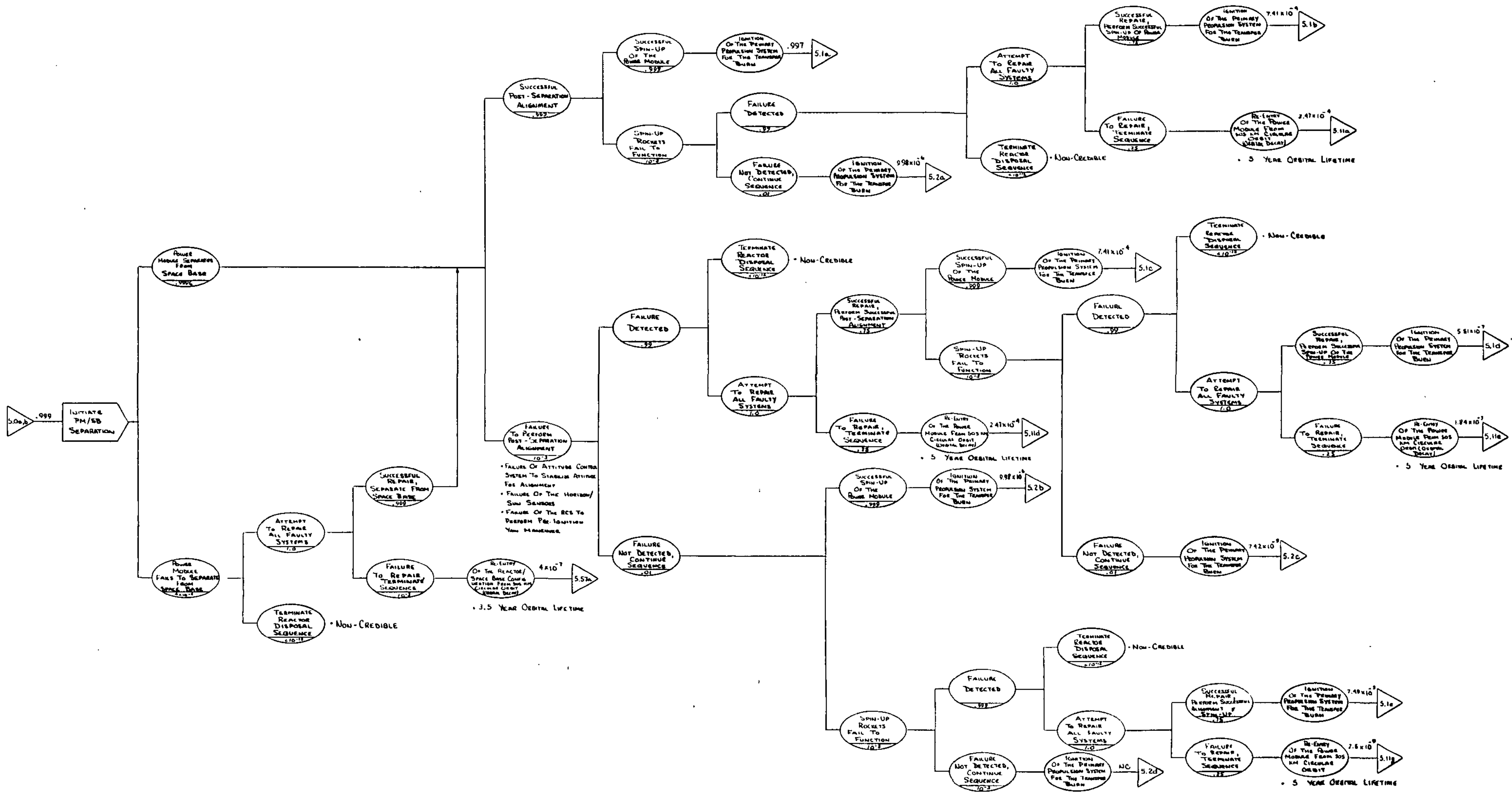
Figure D-52. G & C Equipment Failure Not Detected During Pre-Separation Checkout



D-57 A

Figure D-53. Re-Entry of Damaged Individual Fuel Elements From 500 km Circular Orbit (Orbital Decay)

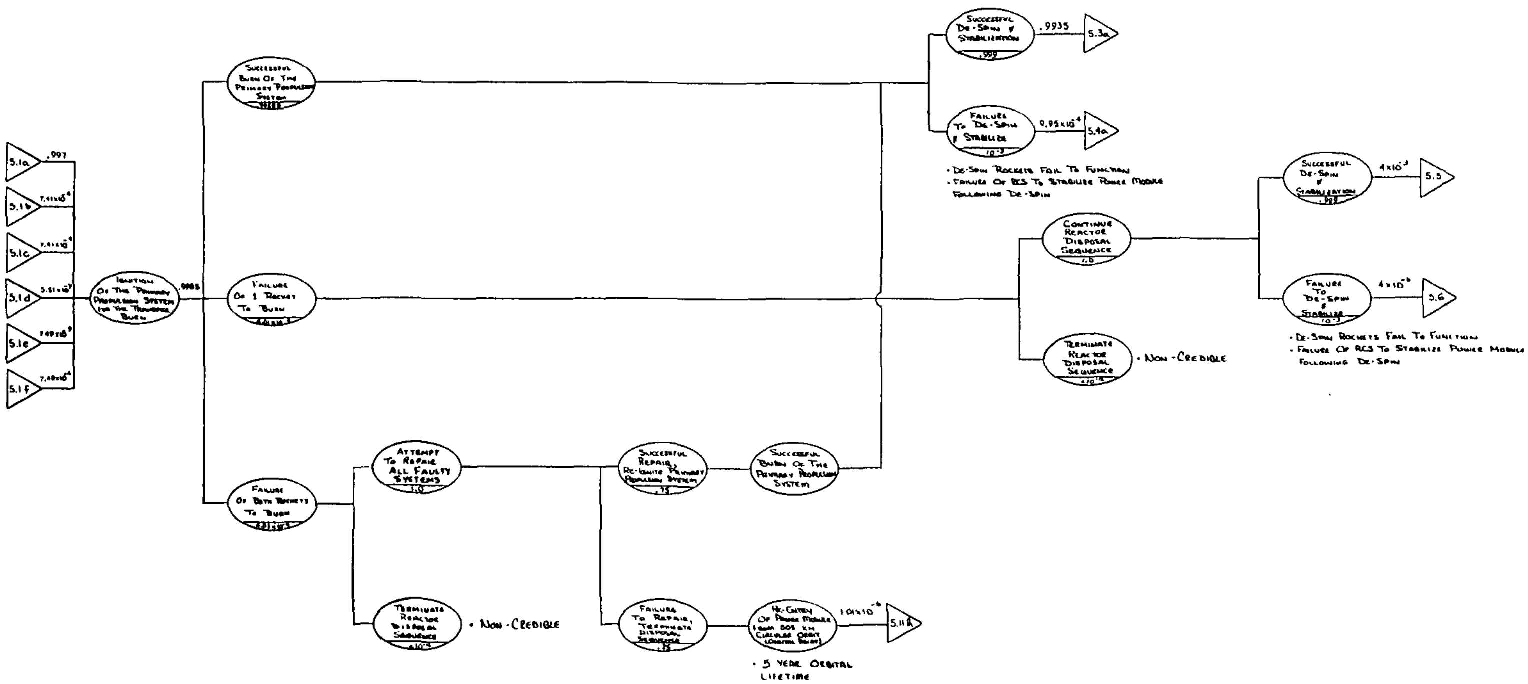
B



D-58 A

D-58 (B)

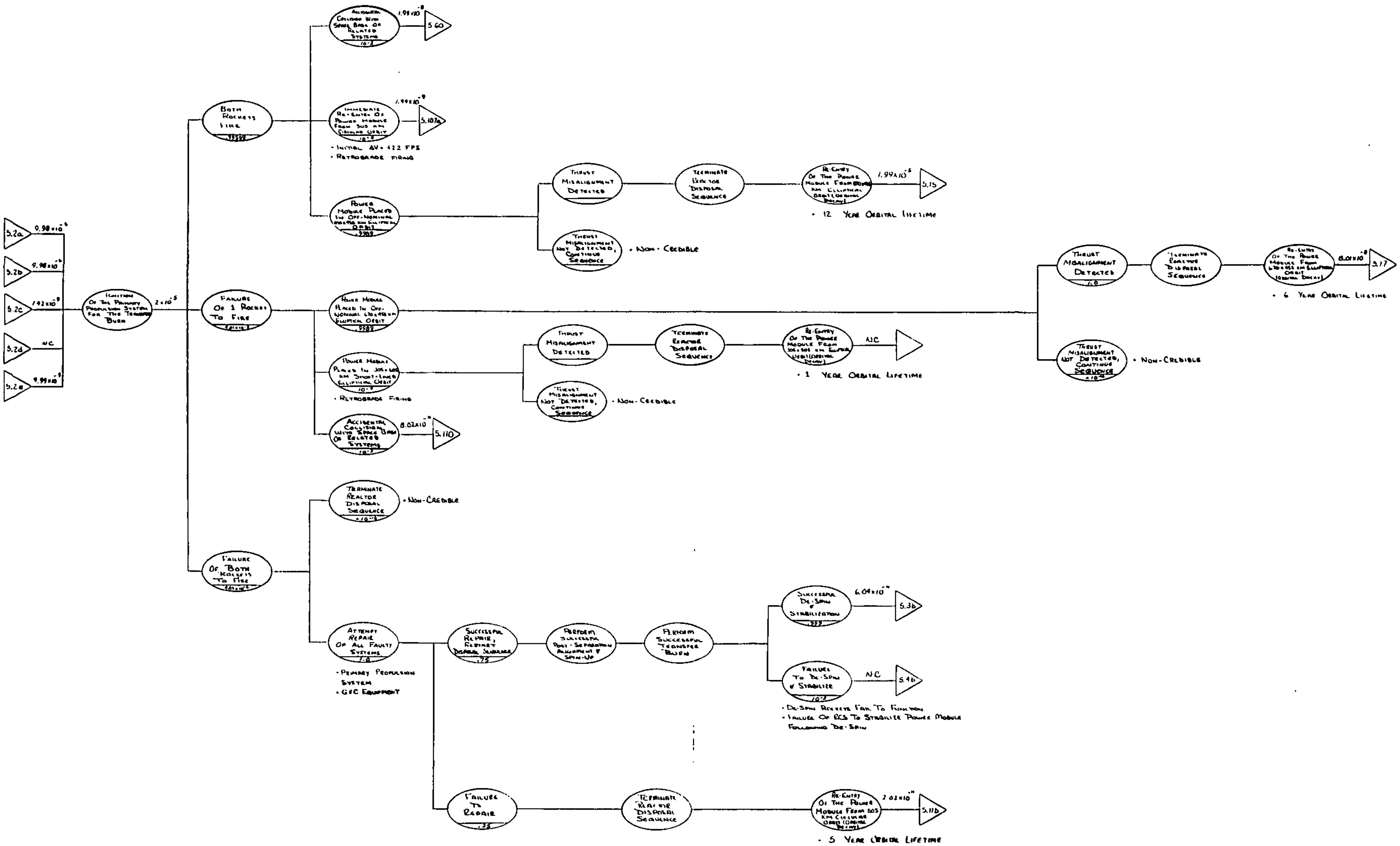
Figure D-54. Initiate PM/SB Separation



D - 59 A

Figure D-55. Ignition of the Primary Propulsion System For Transfer Burn (G & C Functioning Properly)

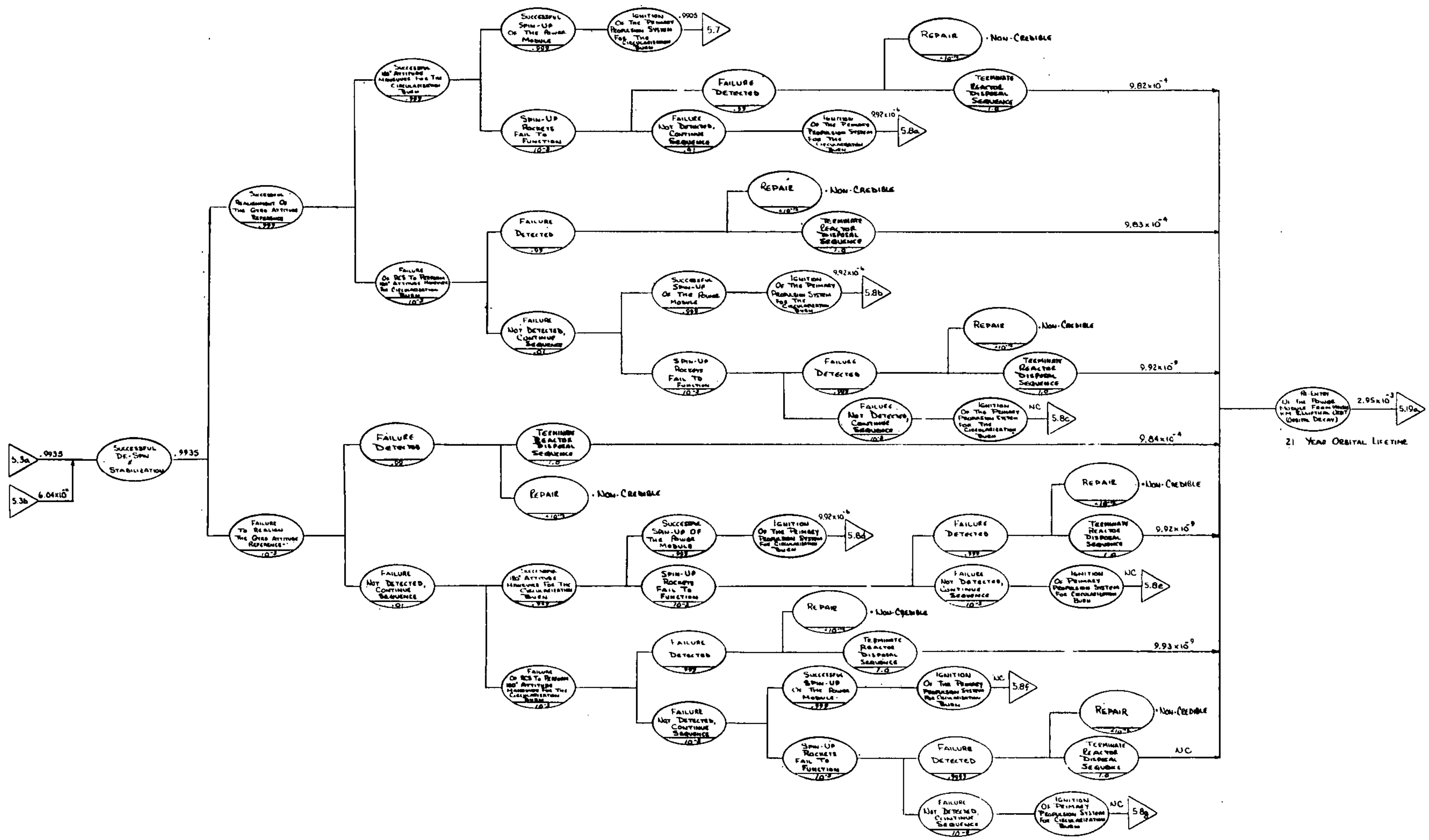
B



D-60 A

(B)

Figure D-56. Ignition of the Primary Propulsion System For Transfer Burn (Undetected G & C Failure Prior to Ignition)



D-61 A

Figure D-57. Successful De-Spin & Stabilization Following Successful 2-Rocket Transfer Burn

(B)

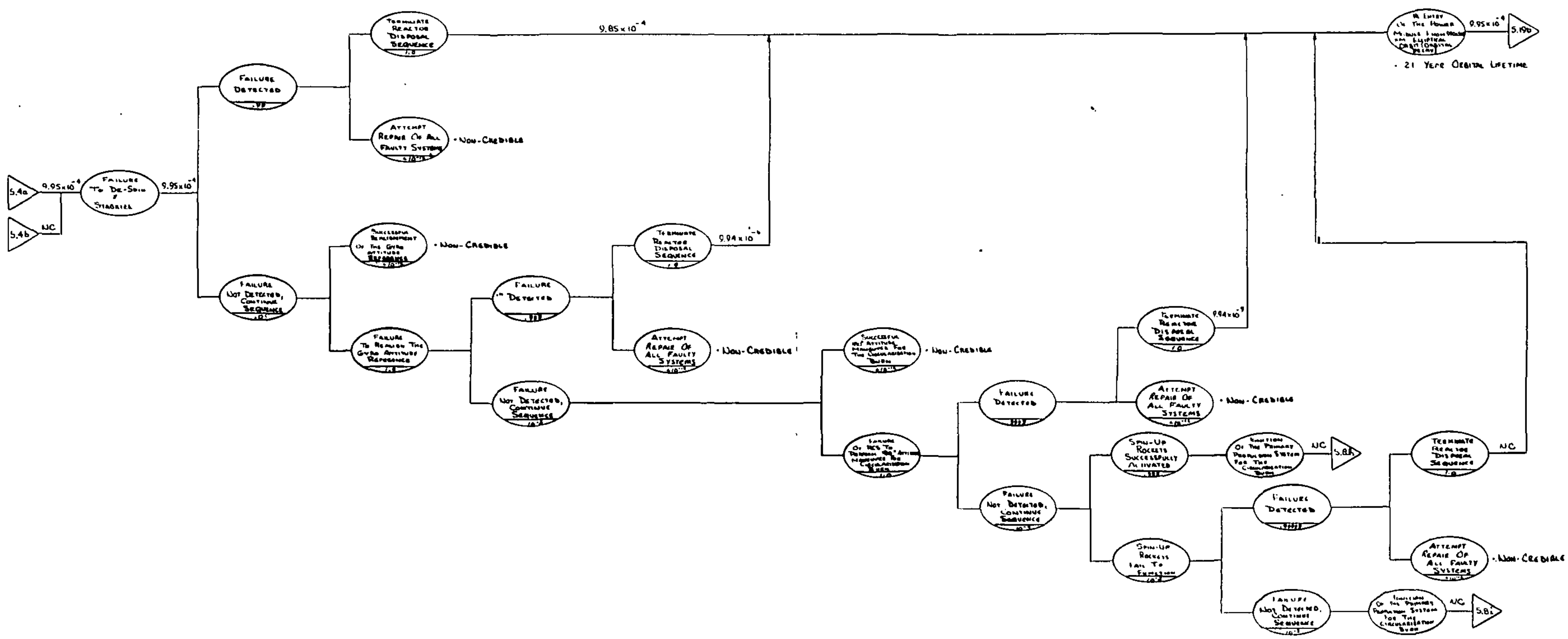
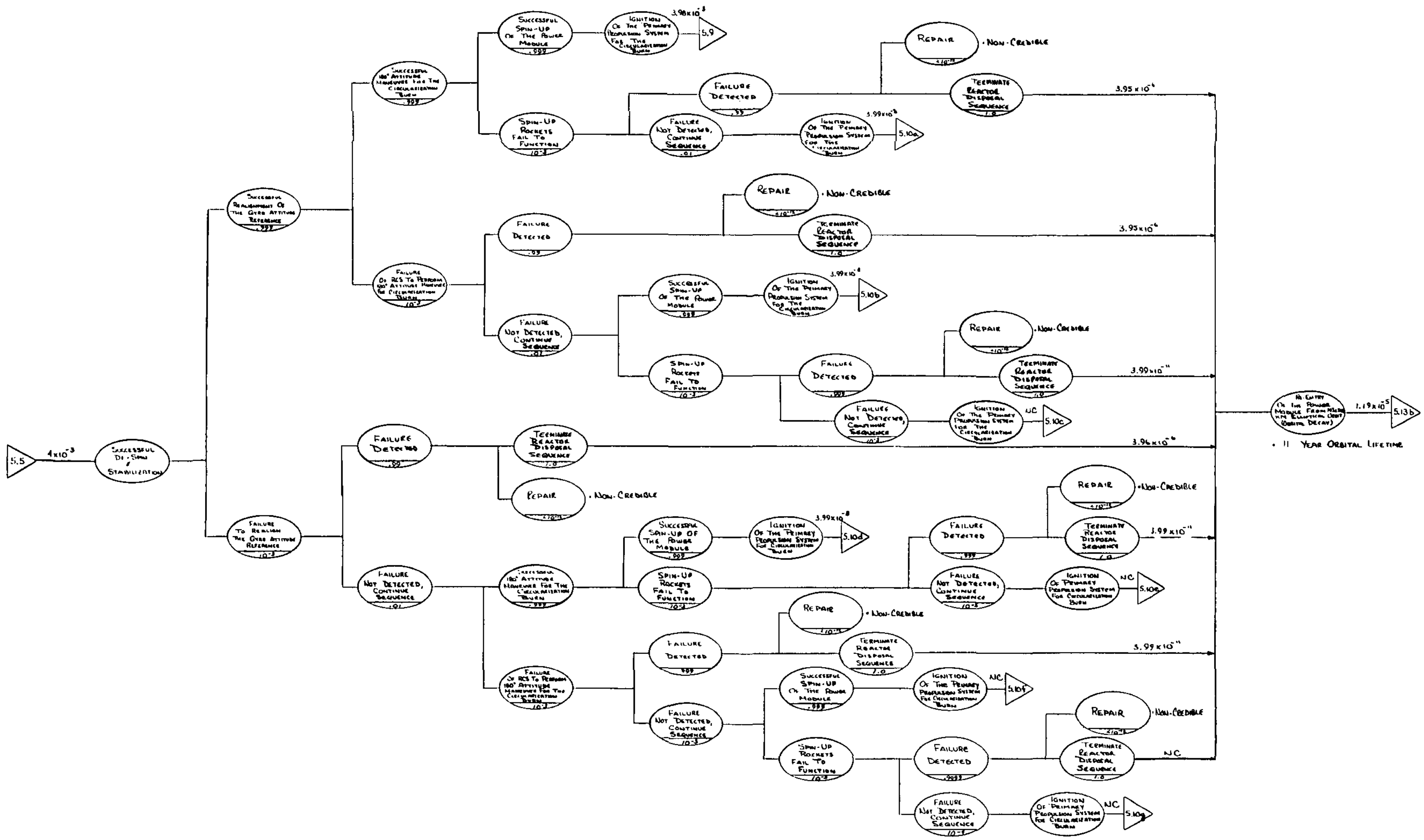


Figure D-58. Failure to De-Spin & Stabilize Following Successful 2-Rocket Transfer Burn

D-62 A

(13)



D-63 A

Figure D-59. Successful De-Spin & Stabilization Following 1 Rocket Transfer Burn

(B)

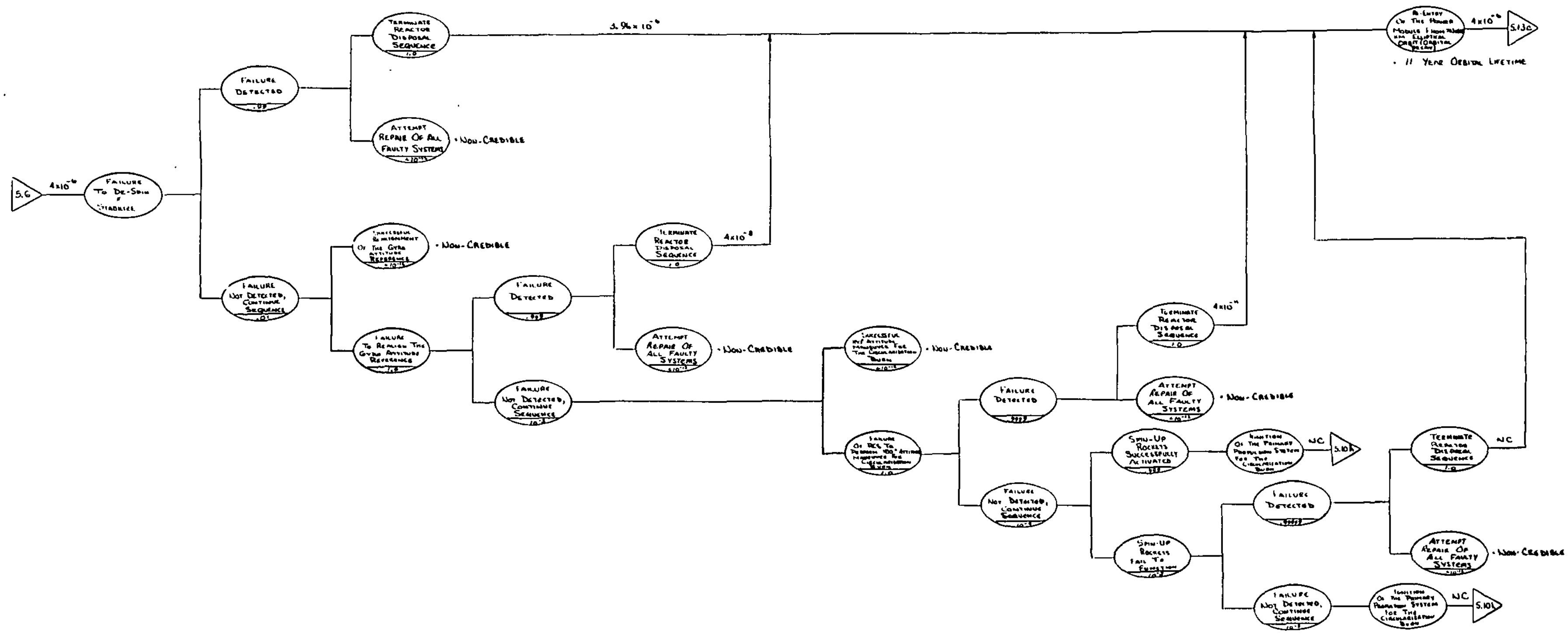
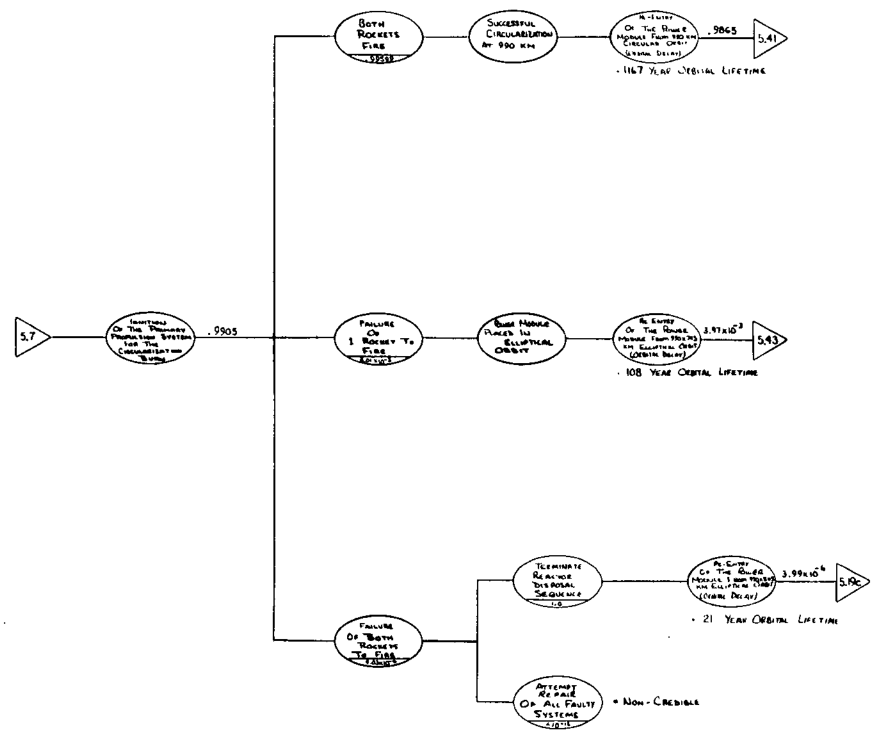


Figure D-60. Failure to De-Spin & Stabilize Following 1 Rocket Transfer Burn

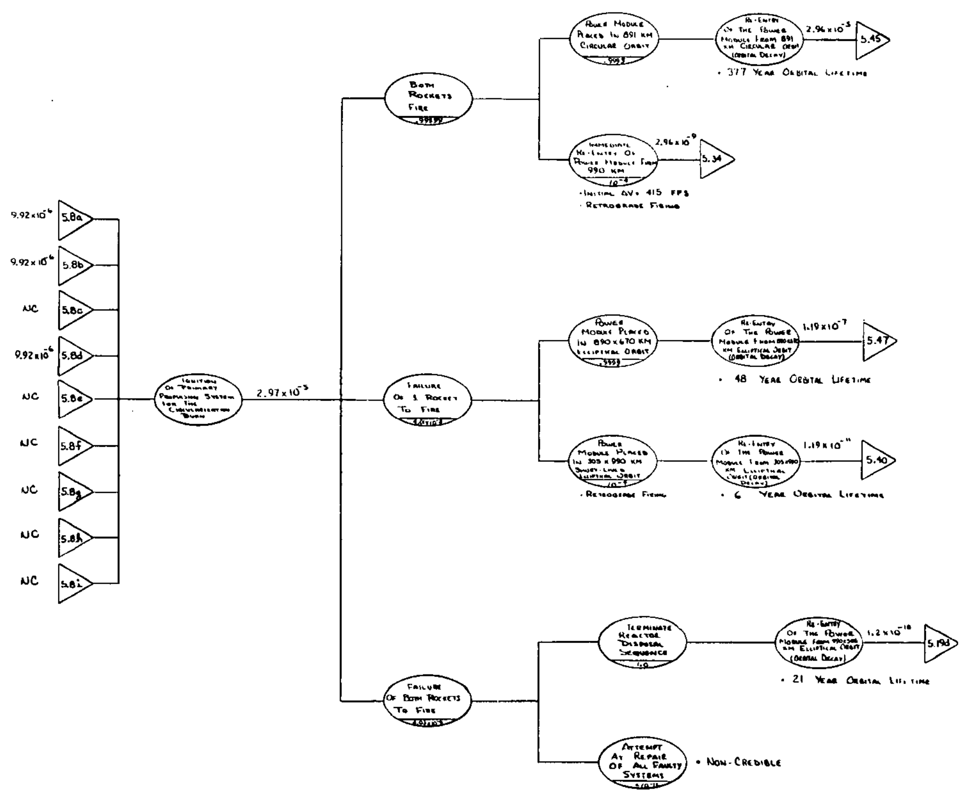
D-64 A



D-65 A

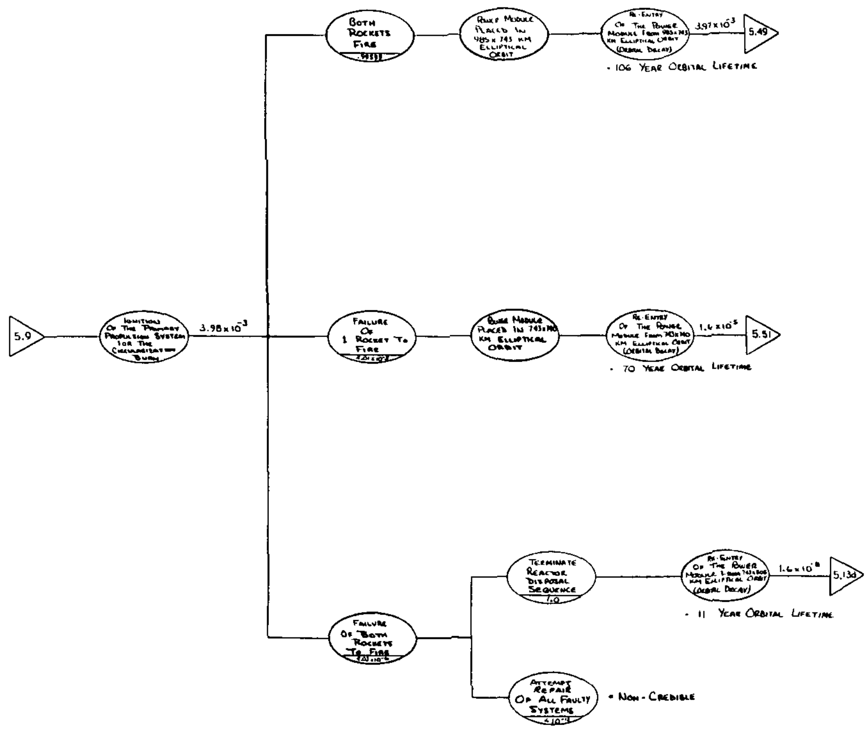
Figure D-61. Ignition of Primary Propulsion System for Circularization Burn Following Successful 2-Rocket Transfer Burn (G&C Functioning Properly)

B



D-66 A

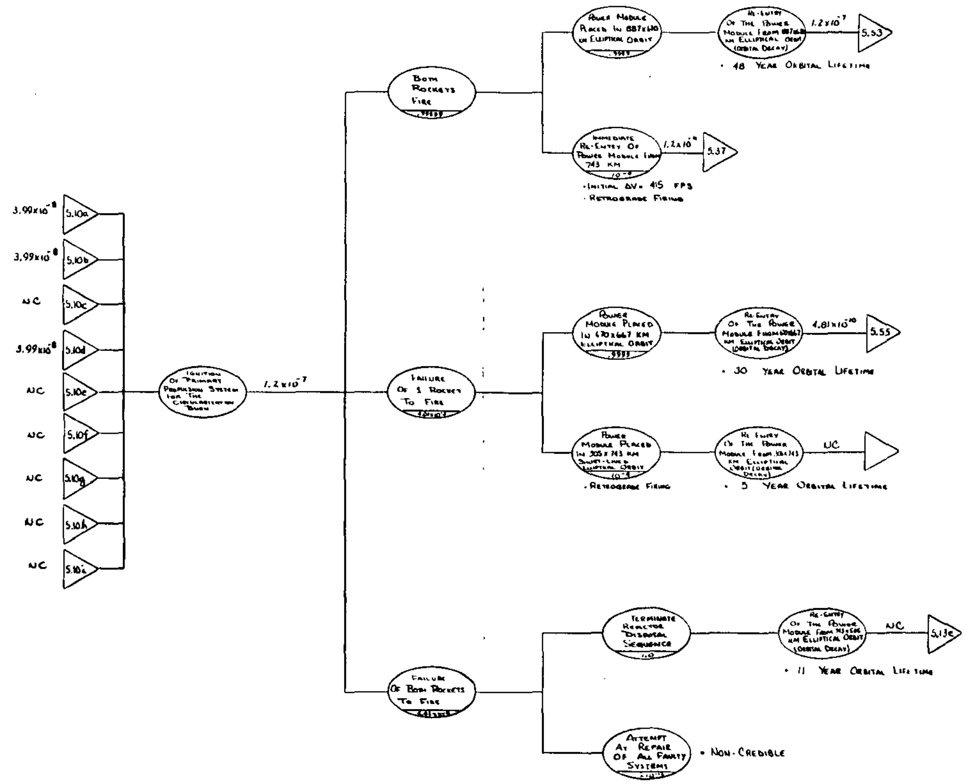
Figure D-62. Ignition of Primary Propulsion System for Circularization Burn Following Successful 2-Rocket Transfer Burn (Undetected G & C Failure Prior to Ignition)



D-67 A

Figure D-63. Ignition of the Primary Propulsion System For Circularization Burn Following 1 Rocket Transfer Burn (G&C Functioning Properly)

B



D-68 A

Figure D-64. Ignition of Primary Propulsion System for Circularization Burn Following 1 Rocket Transfer Burn (Undetected G&C Failure Prior to Ignition)

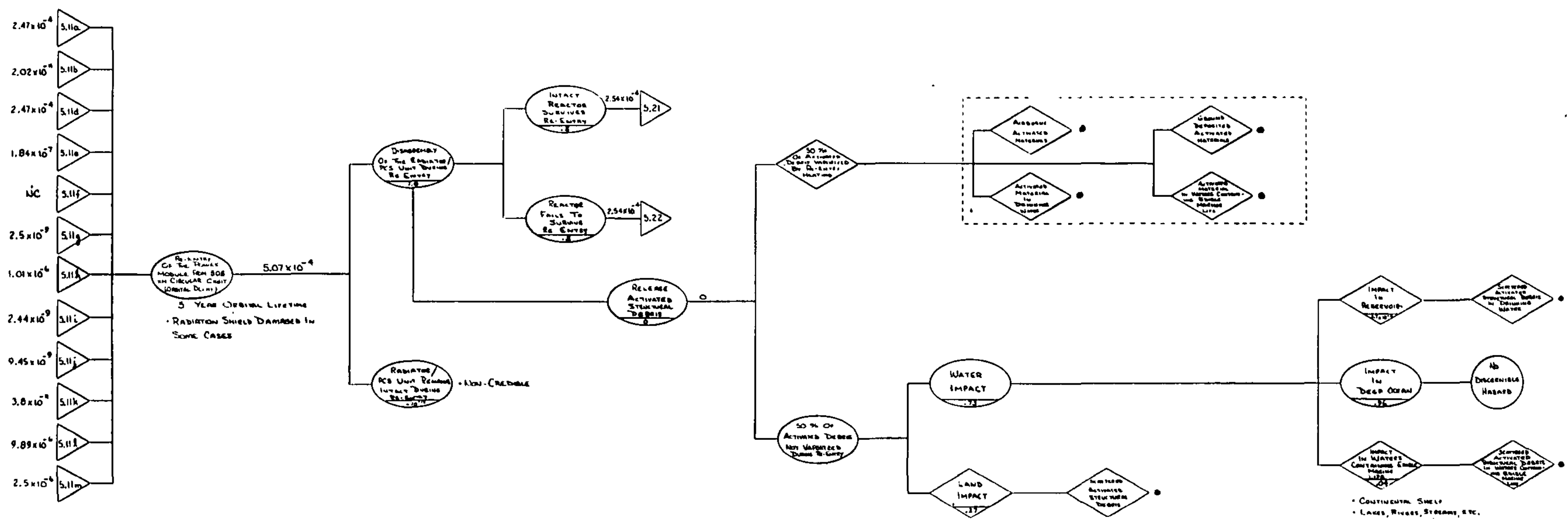
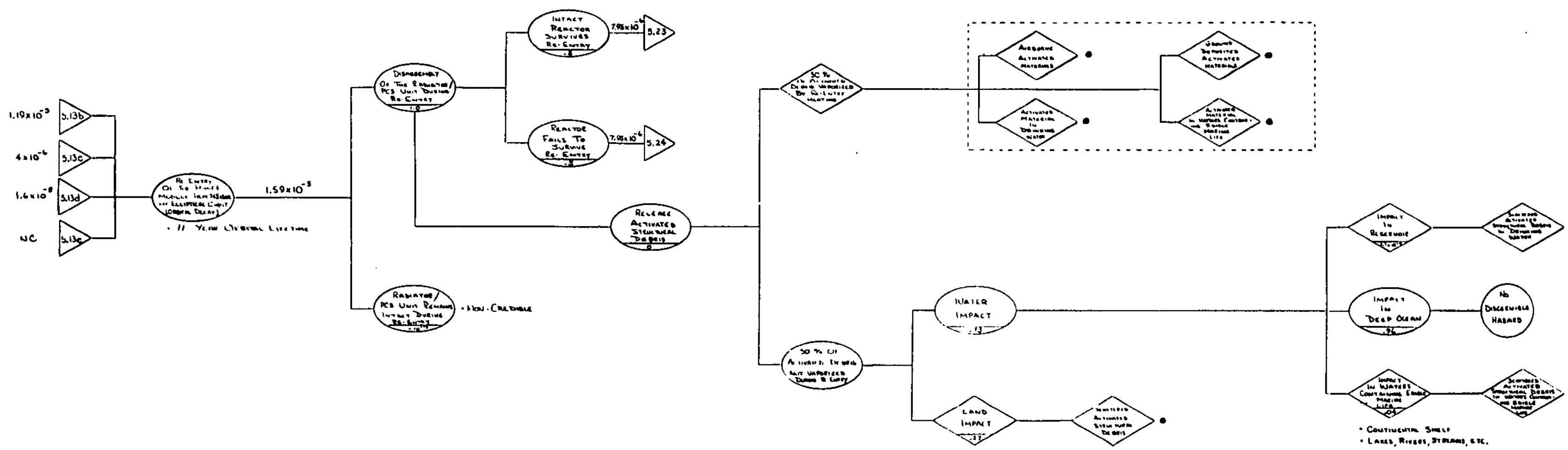


Figure D-65. Re-Entry of PM From 500 km Circular Orbit
(Orbital Decay)

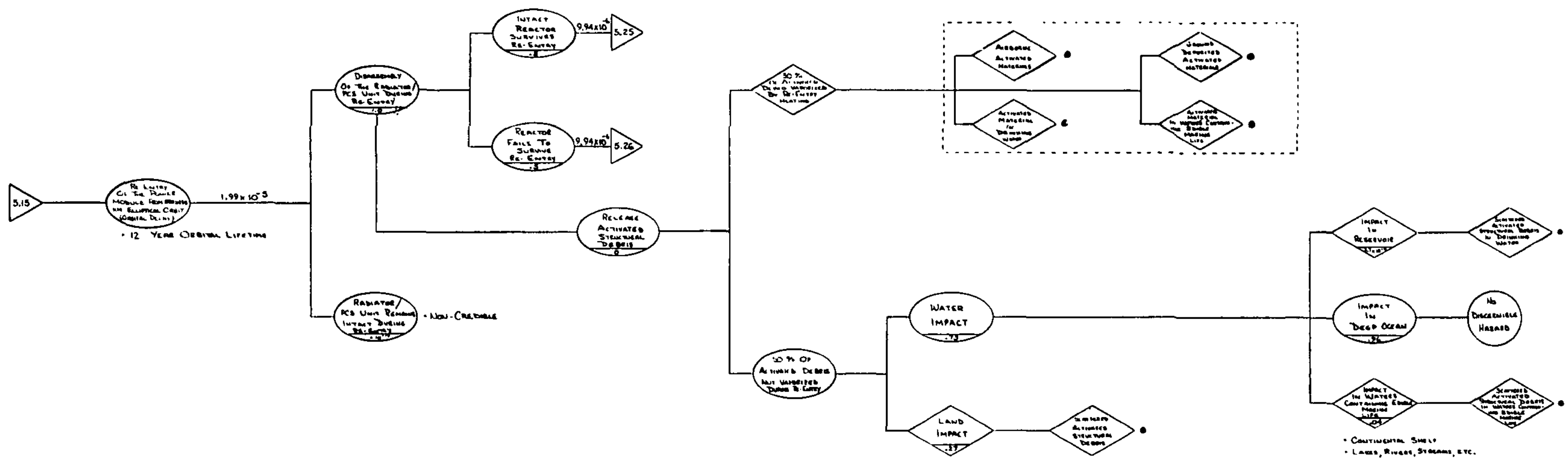
D-69 A

(B)



D-70 A

Figure D-66. Re-Entry of PM From 743 x 500 km Elliptical Orbit (Orbital Decay)



D-71 (A)

Figure D-67. Re-Entry of PM From 890 x 455 km Elliptical Orbit (Orbital Decay)

(B)

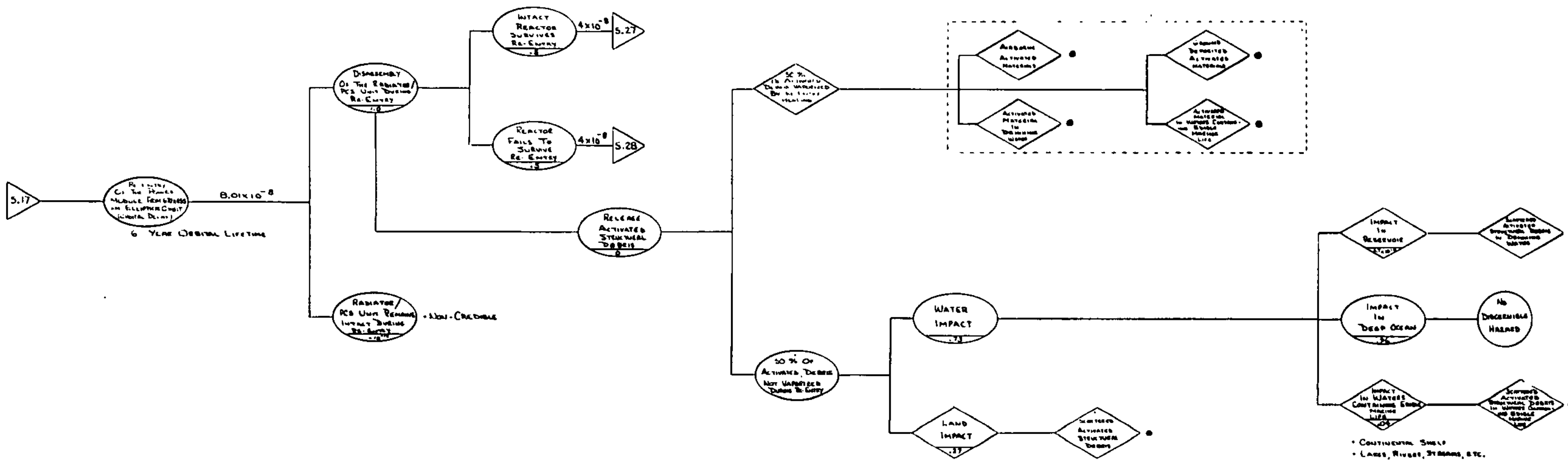
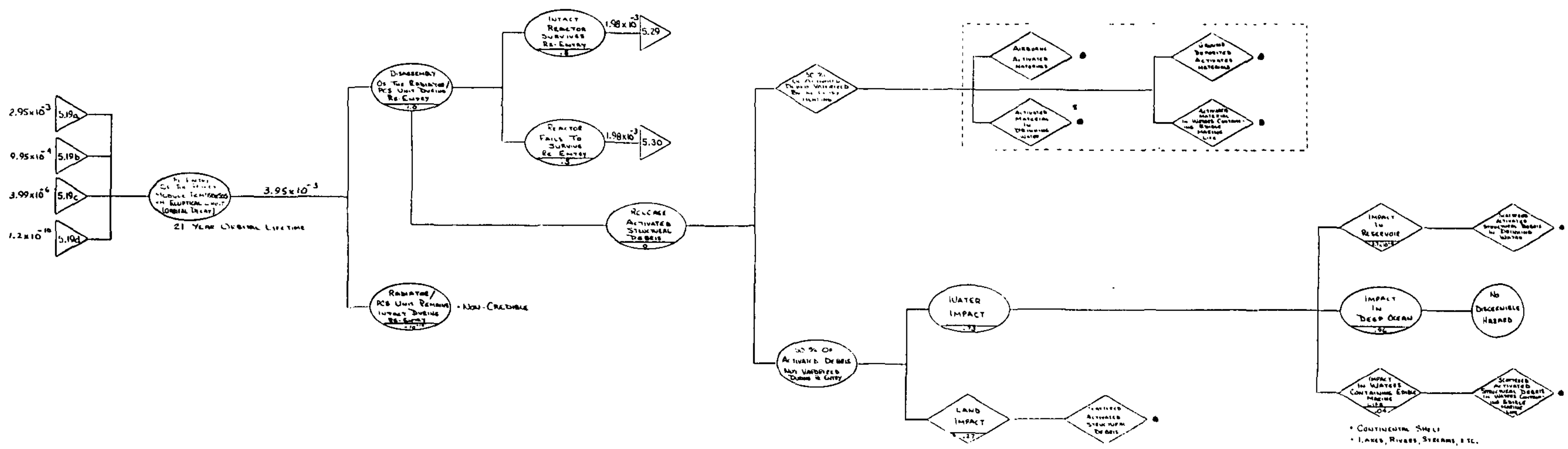


Figure D-68. Re-Entry of PM From 670 x 455 km Elliptical Orbit (Orbital Decay)

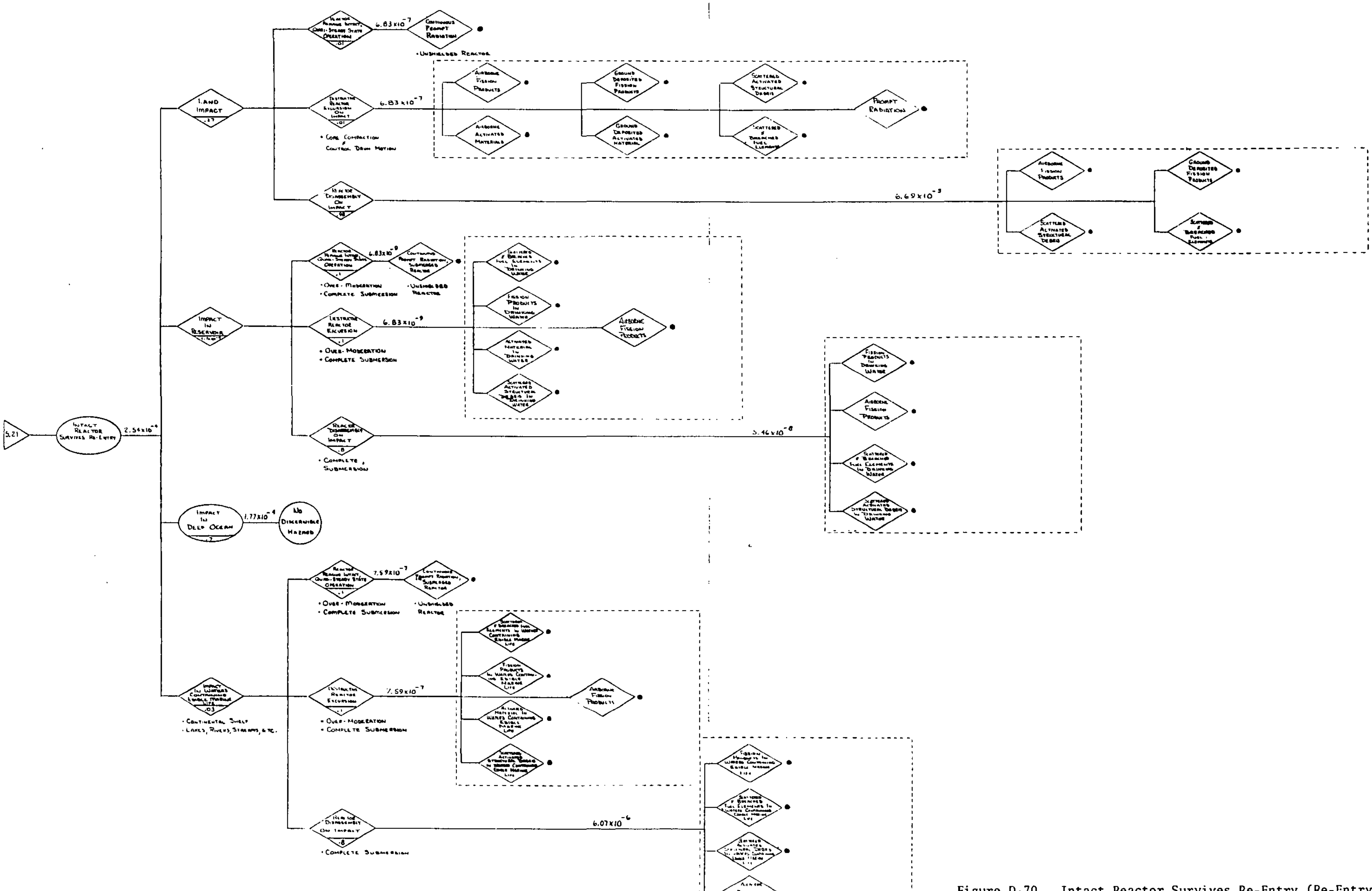
D-72 A



D-73 (A)

Figure D-69. Re-Entry of PM From 990 x 500 km Elliptical Orbit (Orbital Decay)

(B)



D-74 (A)

Figure D-70. Intact Reactor Survives Re-Entry (Re-Entry of PM From 500 km Circular Orbit, Orbital Decay)

(B)

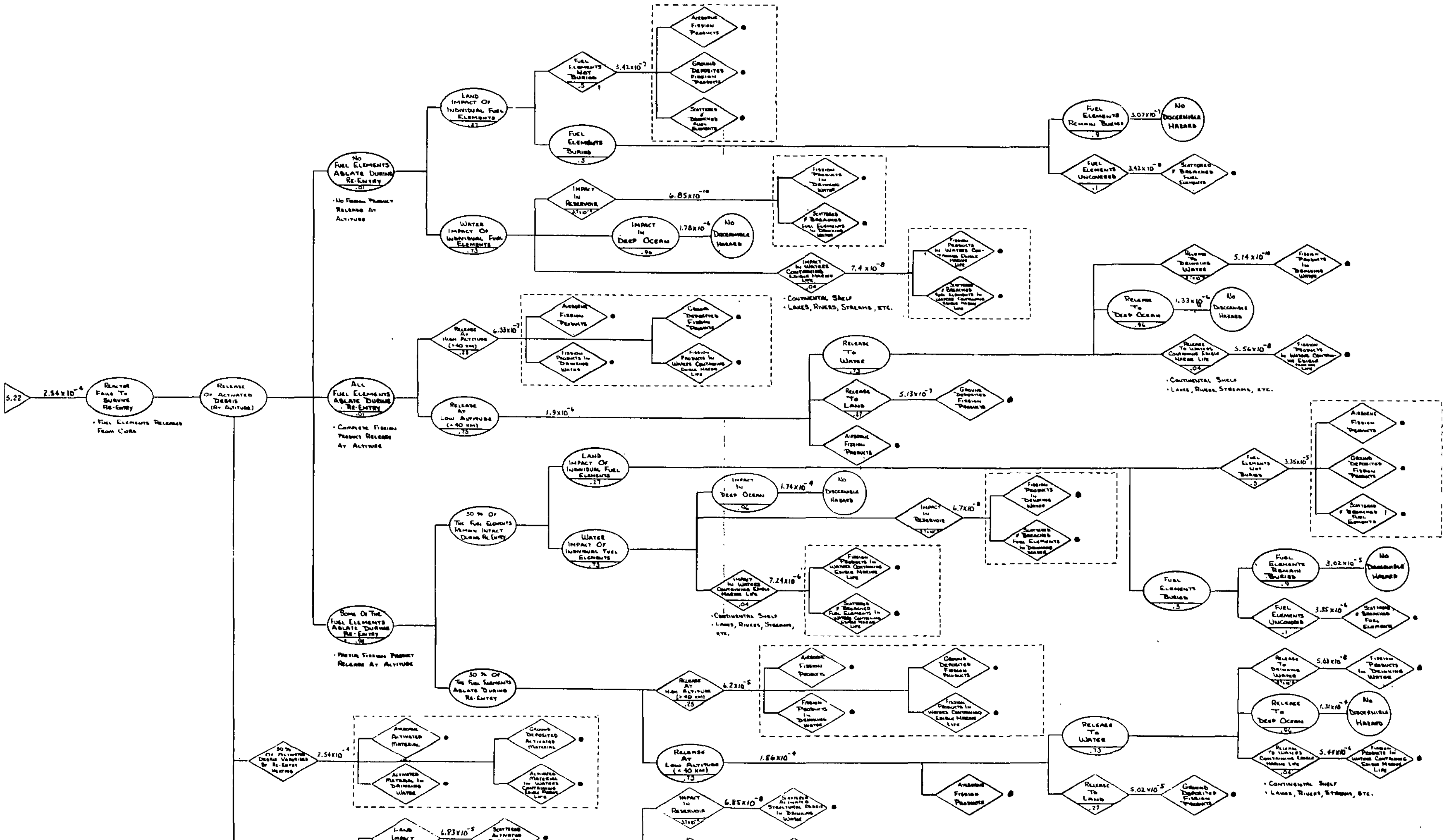


Figure D-71. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 500 km Circular Orbit, Orbital Decay)

D-75 (A)

(B)

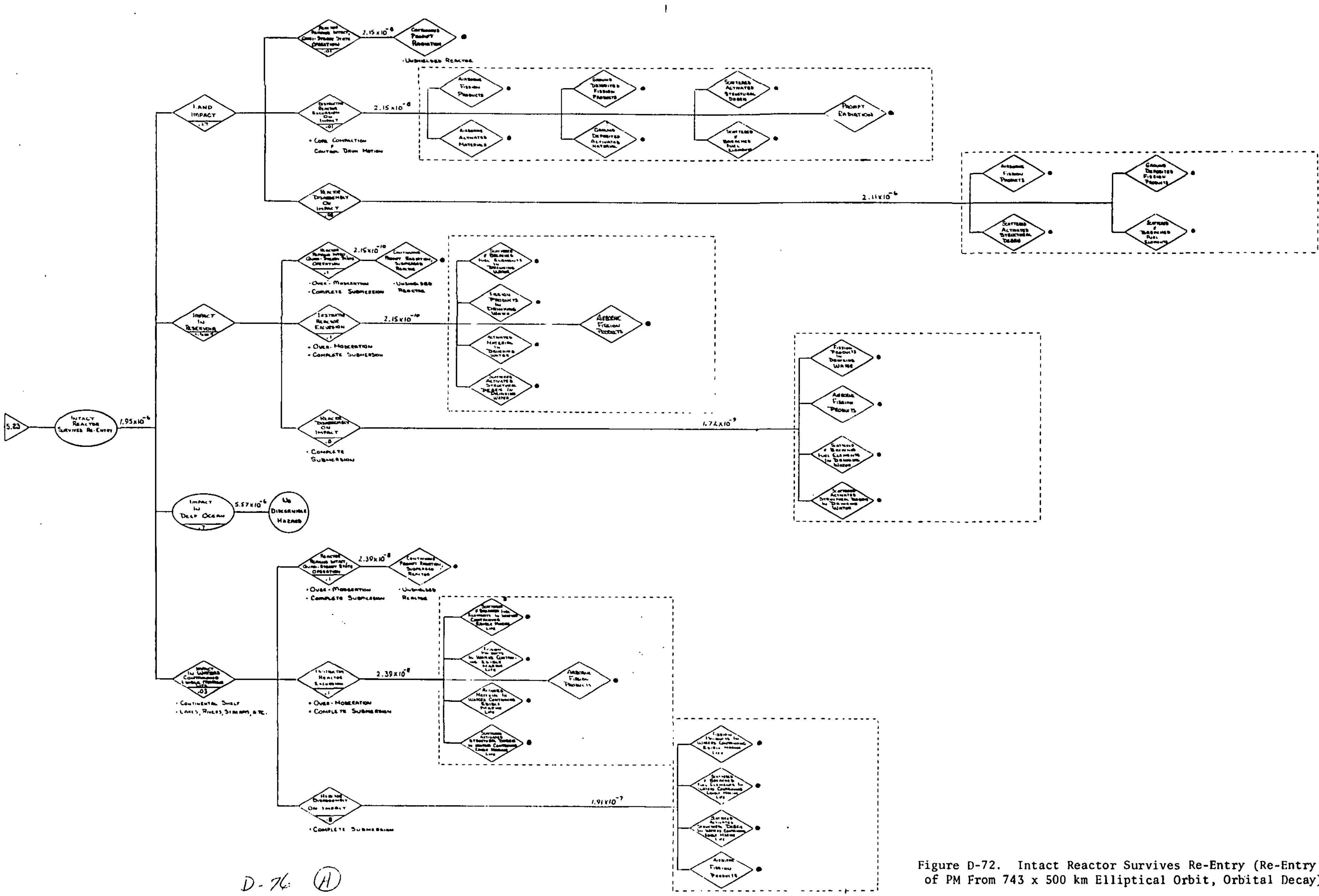


Figure D-72. Intact Reactor Survives Re-Entry (Re-Entry of PM From 743 x 500 km Elliptical Orbit, Orbital Decay)

D-76 (A)

(B)

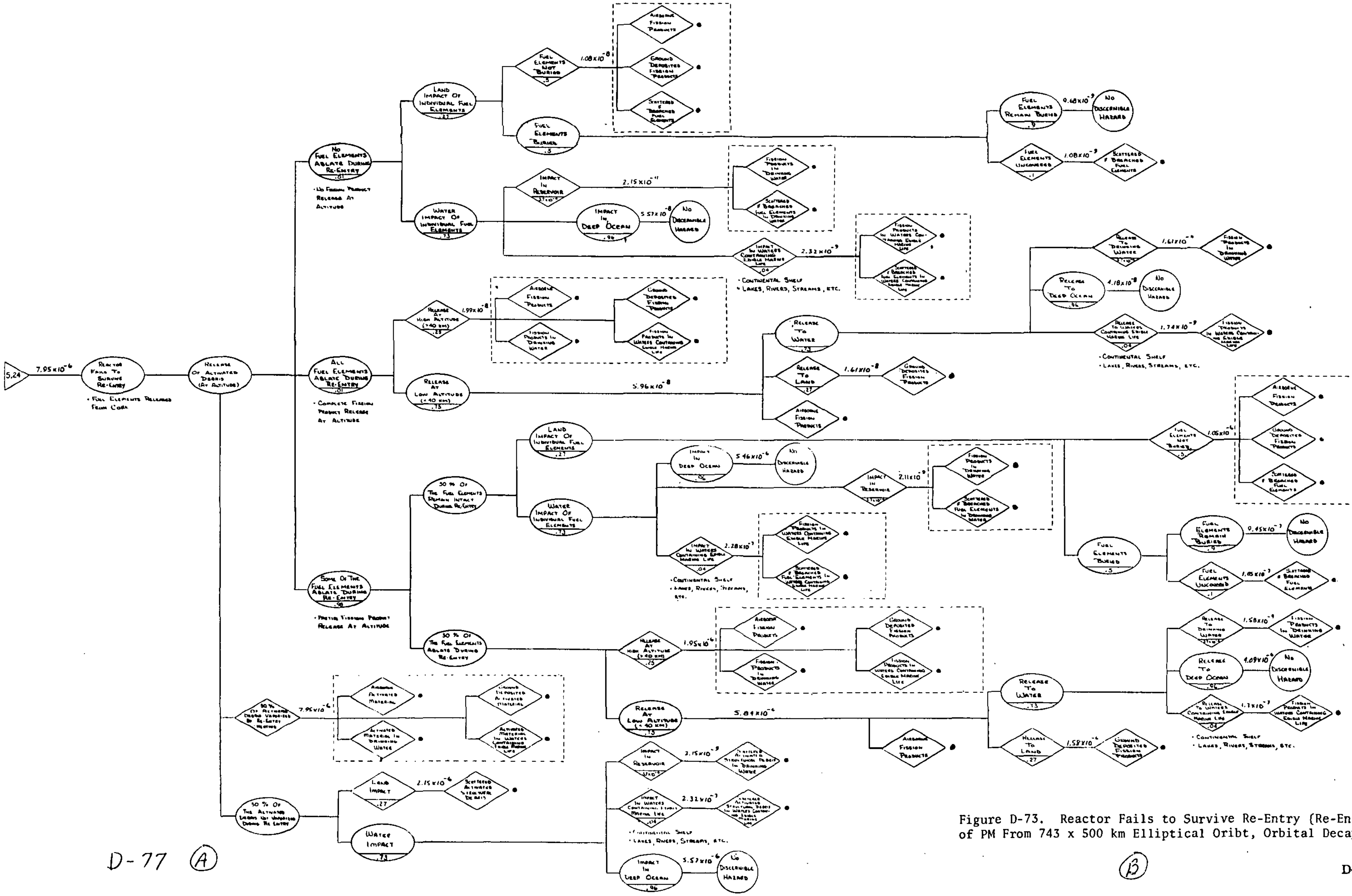
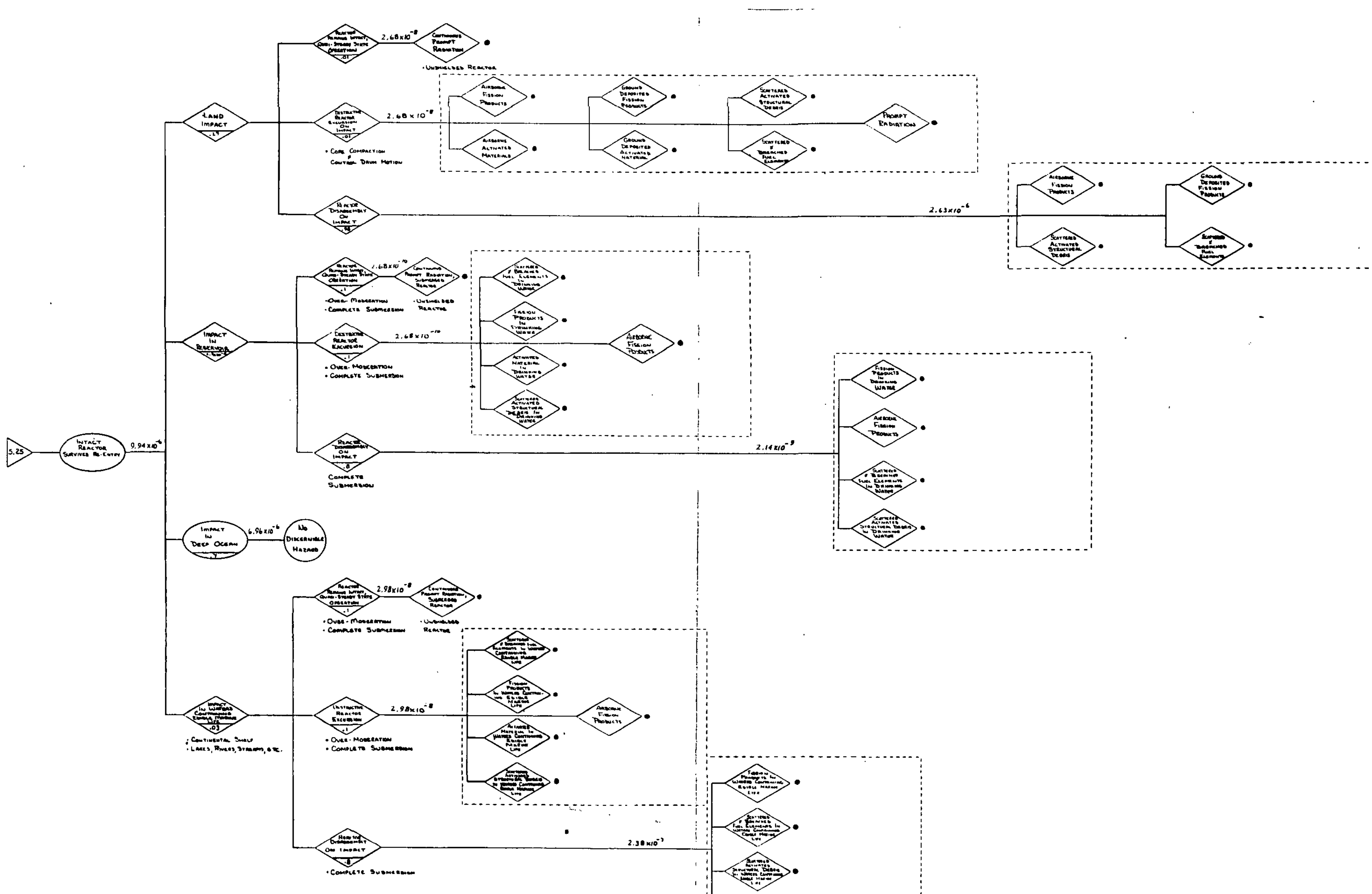


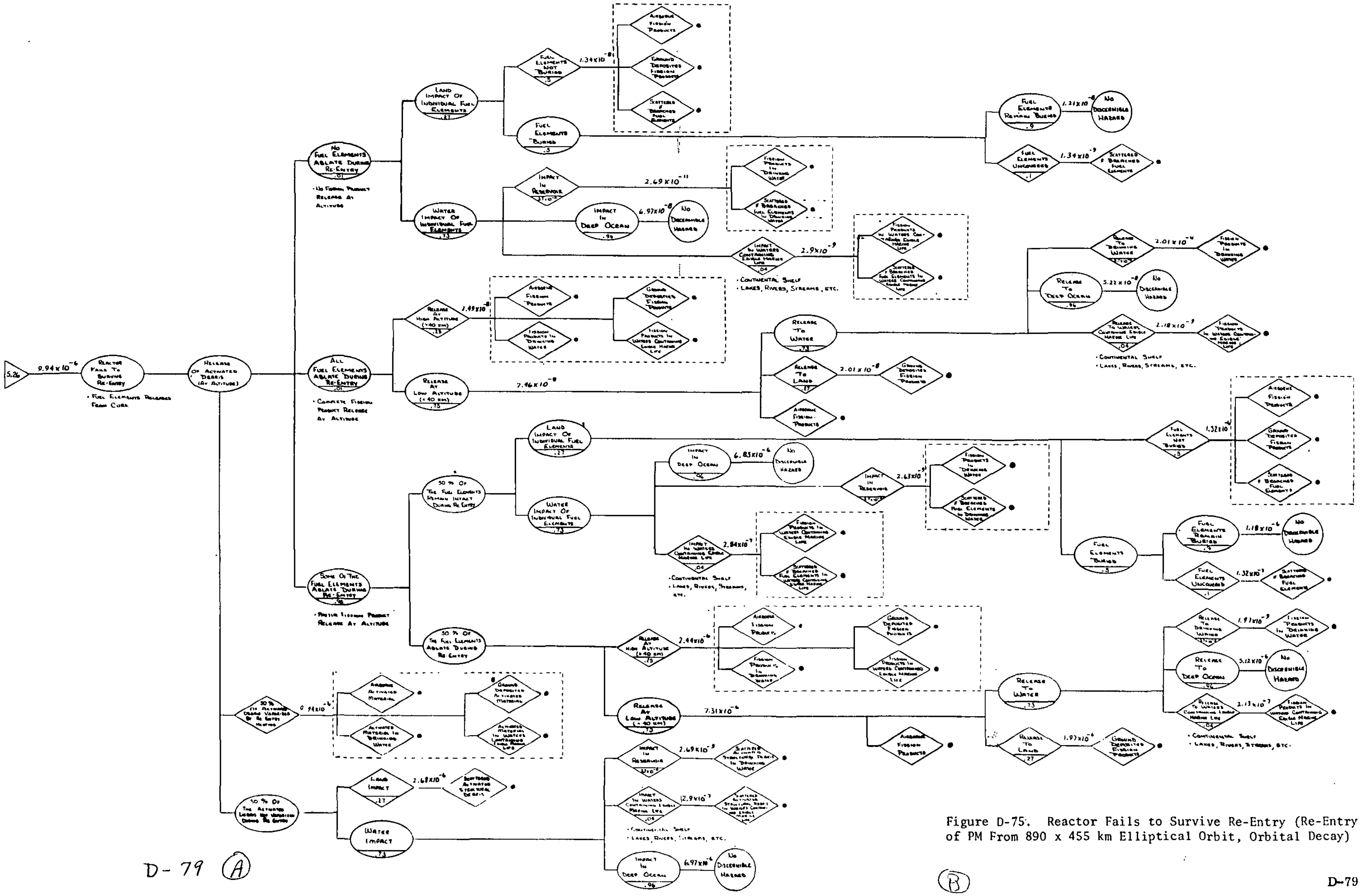
Figure D-73. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 743 x 500 km Elliptical Oribt, Orbital Decay)



D-78 (A)

Figure D-74. Intact Reactor Survives Re-Entry (Re-Entry of PM From 890 x 455 km Elliptical Orbit, Orbital Decay)

(B)



D- 79 (A)

Figure D-75. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 890 x 455 km Elliptical Orbit, Orbital Decay)

(B)

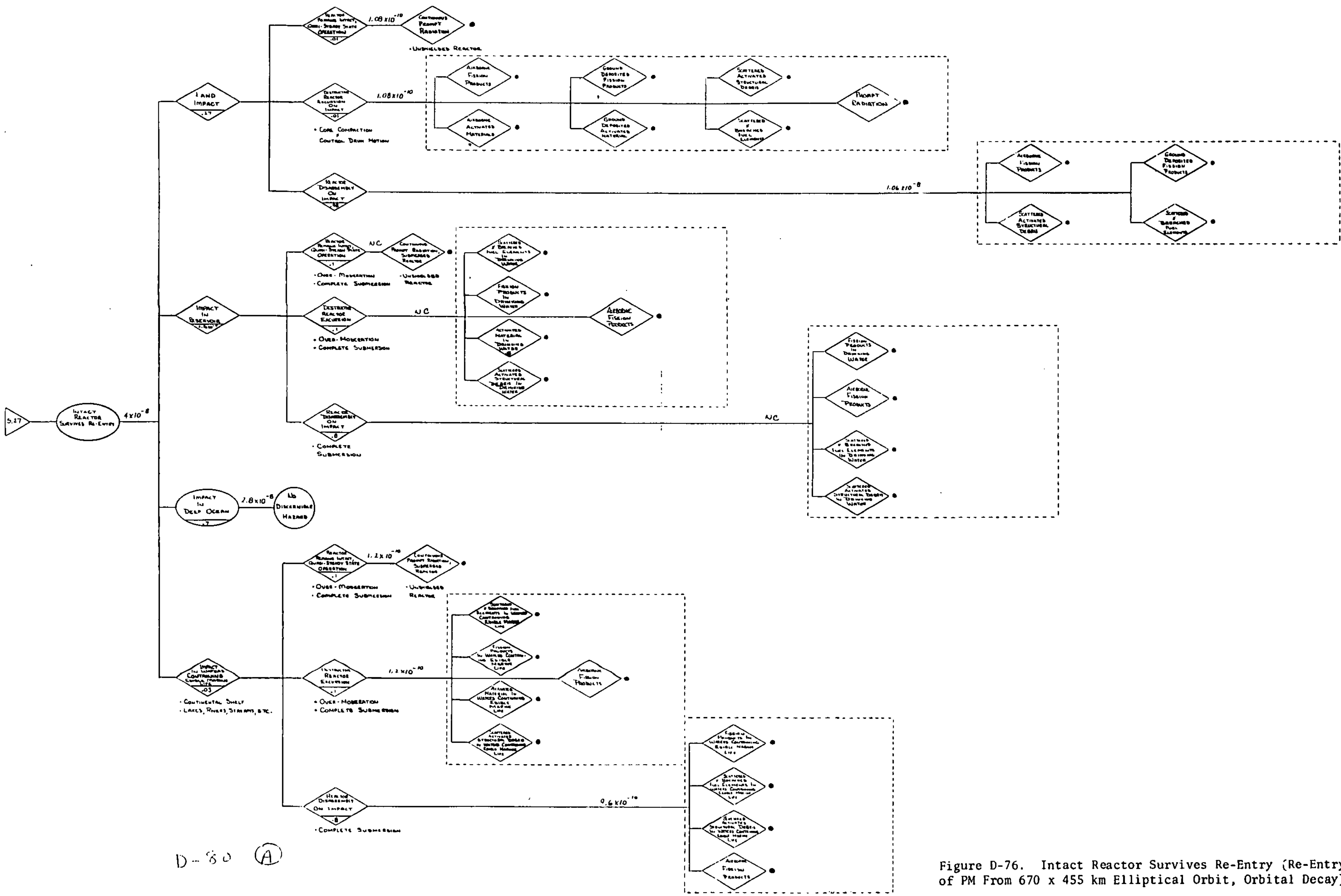
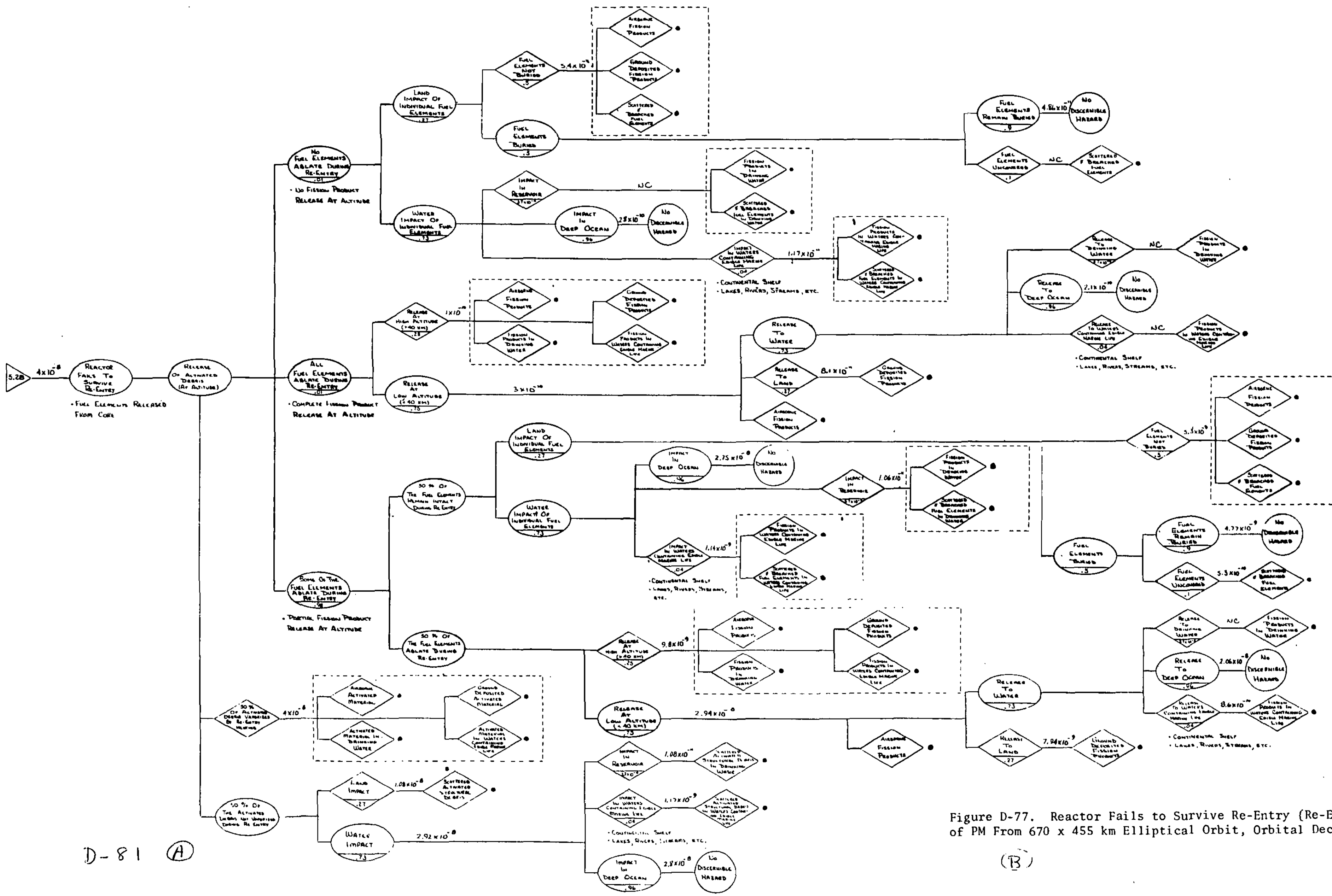


Figure D-76. Intact Reactor Survives Re-Entry (Re-Entry of PM From 670 x 455 km Elliptical Orbit, Orbital Decay)

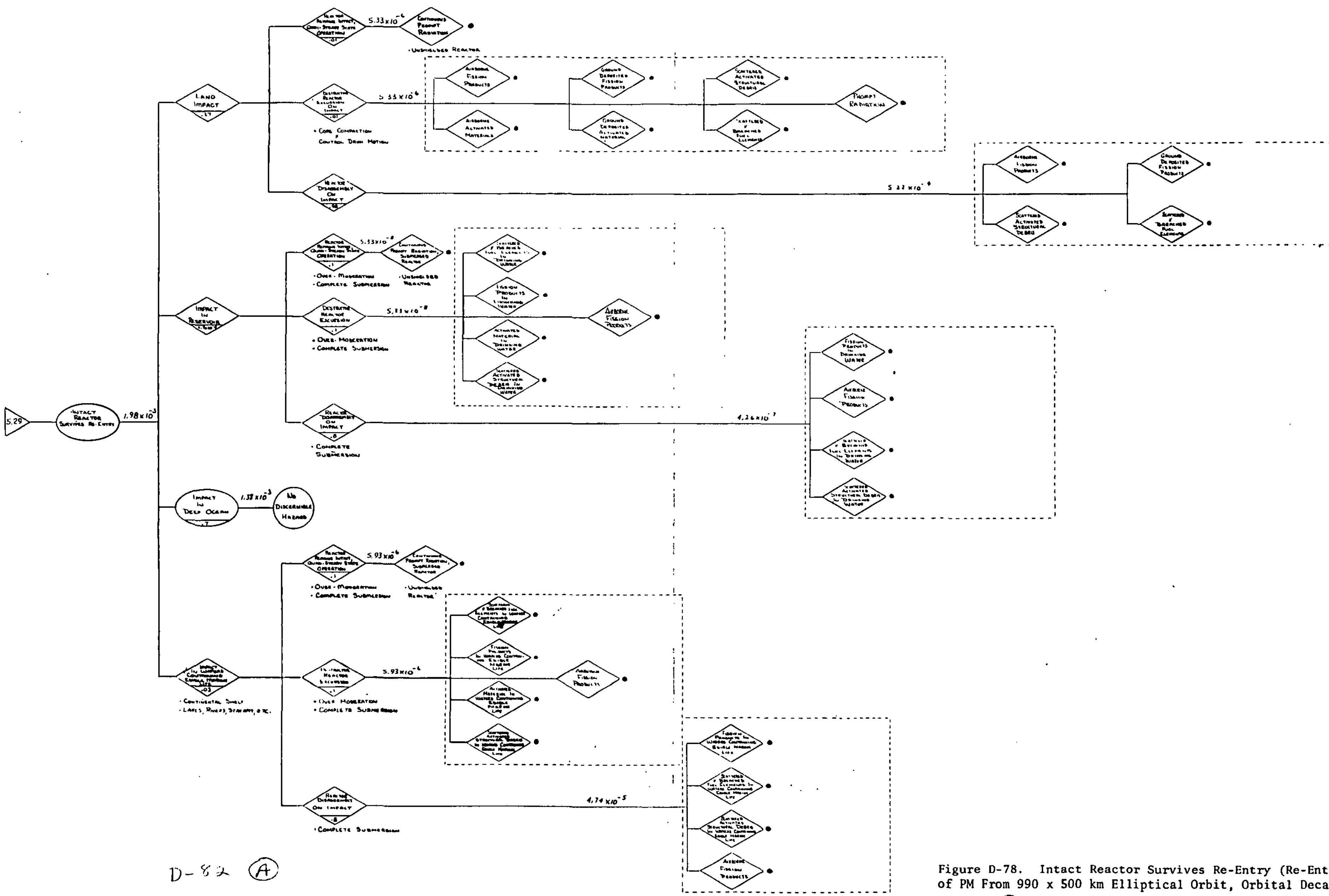
(B)



D-81 (A)

Figure D-77. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 670 x 455 km Elliptical Orbit, Orbital Decay)

(B)



D-82 (A)

Figure D-78. Intact Reactor Survives Re-Entry (Re-Entry of PM From 990 x 500 km Elliptical Orbit, Orbital Decay)

(B)

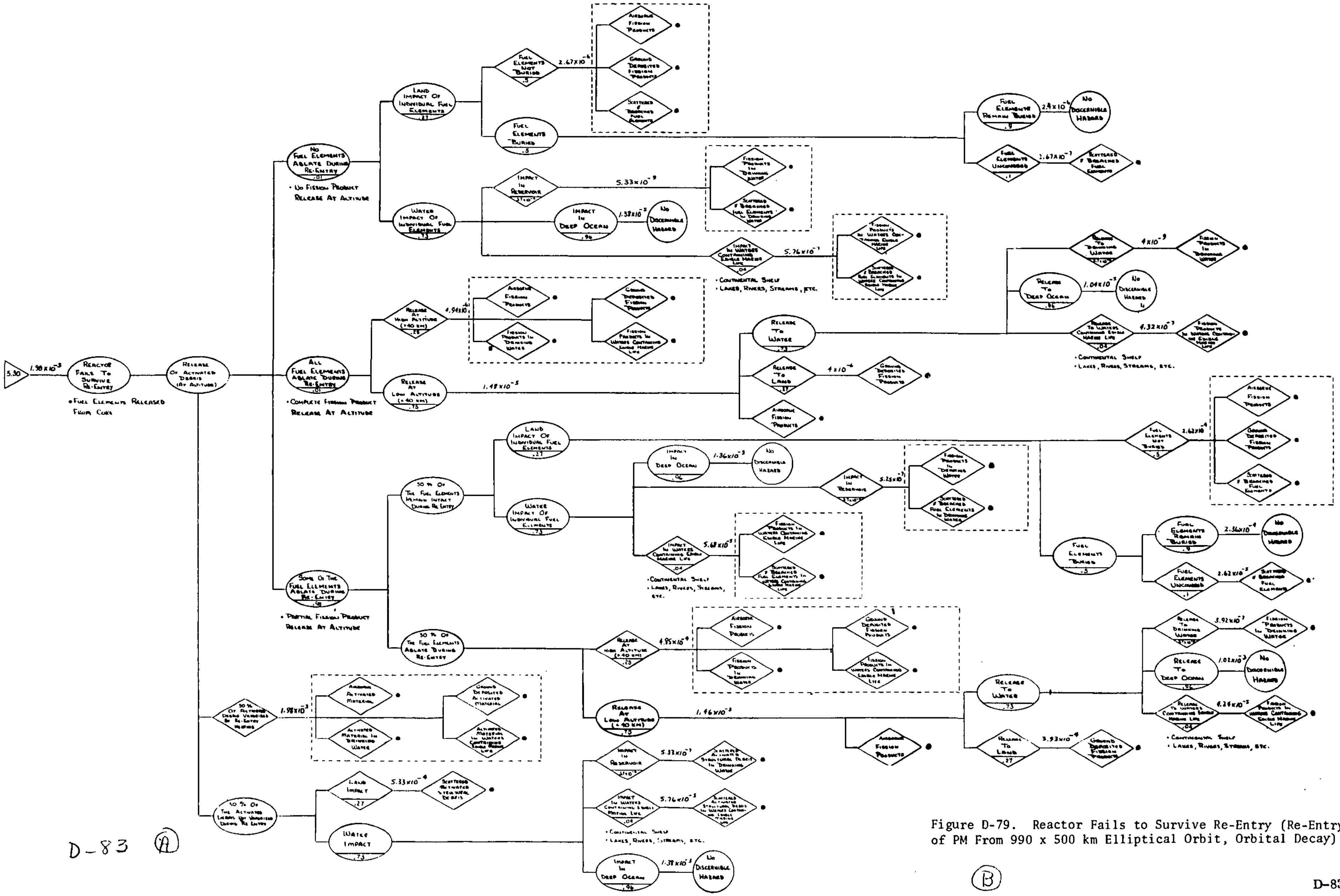
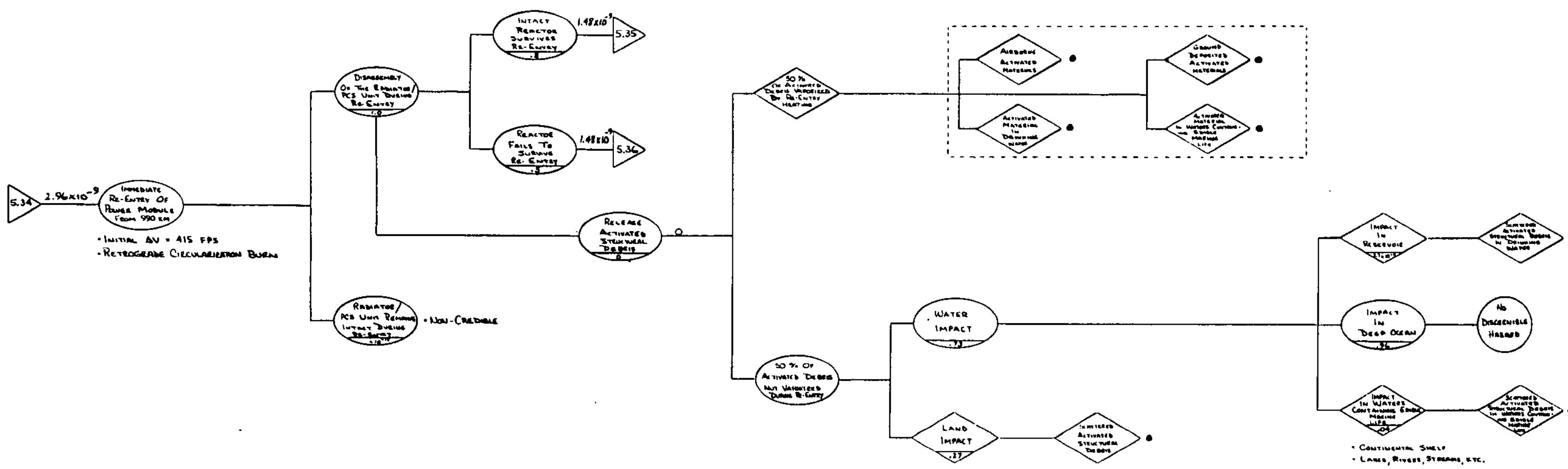


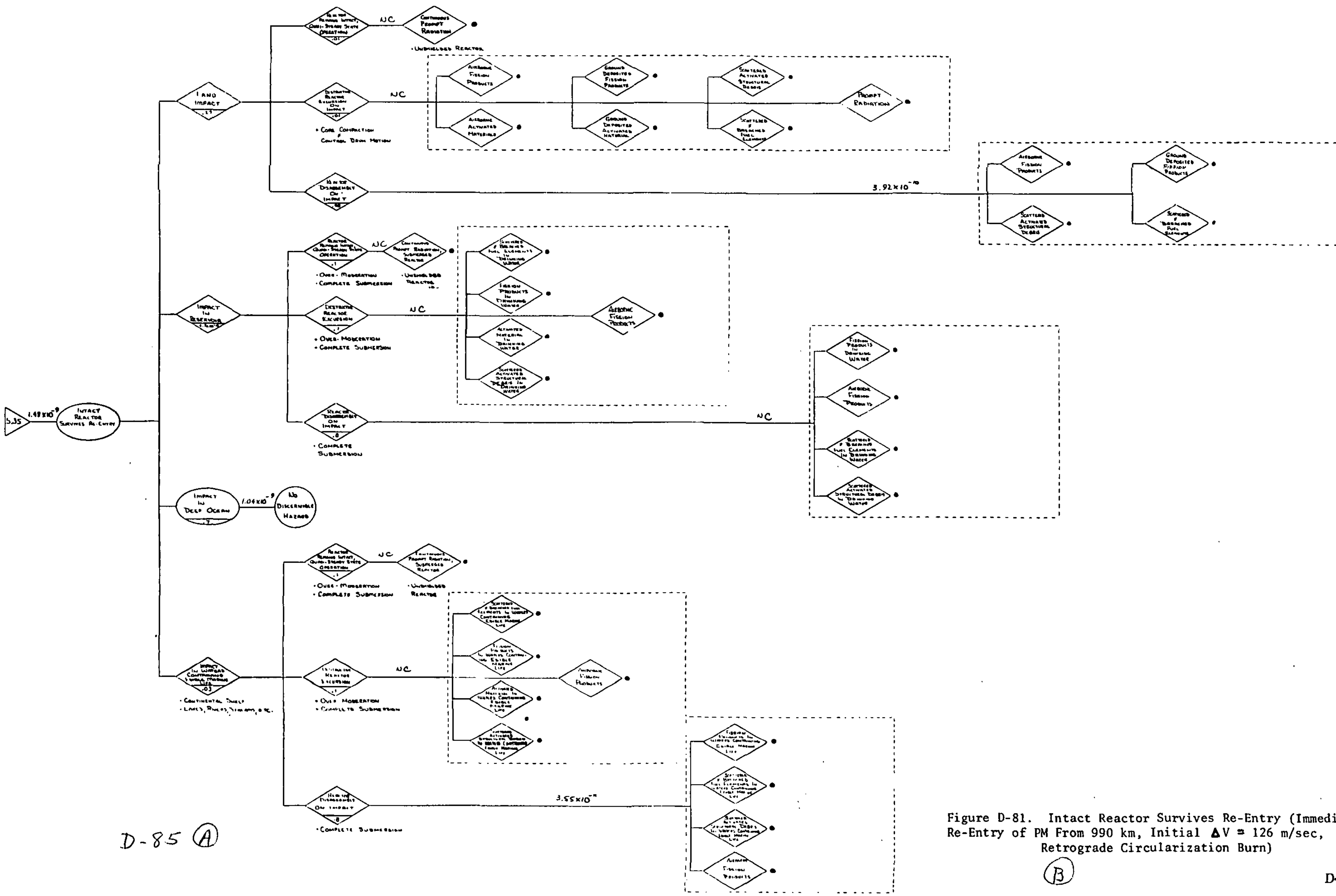
Figure D-79. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 990 x 500 km Elliptical Orbit, Orbital Decay)



D-84 (A)

Figure D-80. Immediate Re-Entry of PM From 990 km, Initial ΔV = 126 m/sec (Retrograde Circularization Burn)

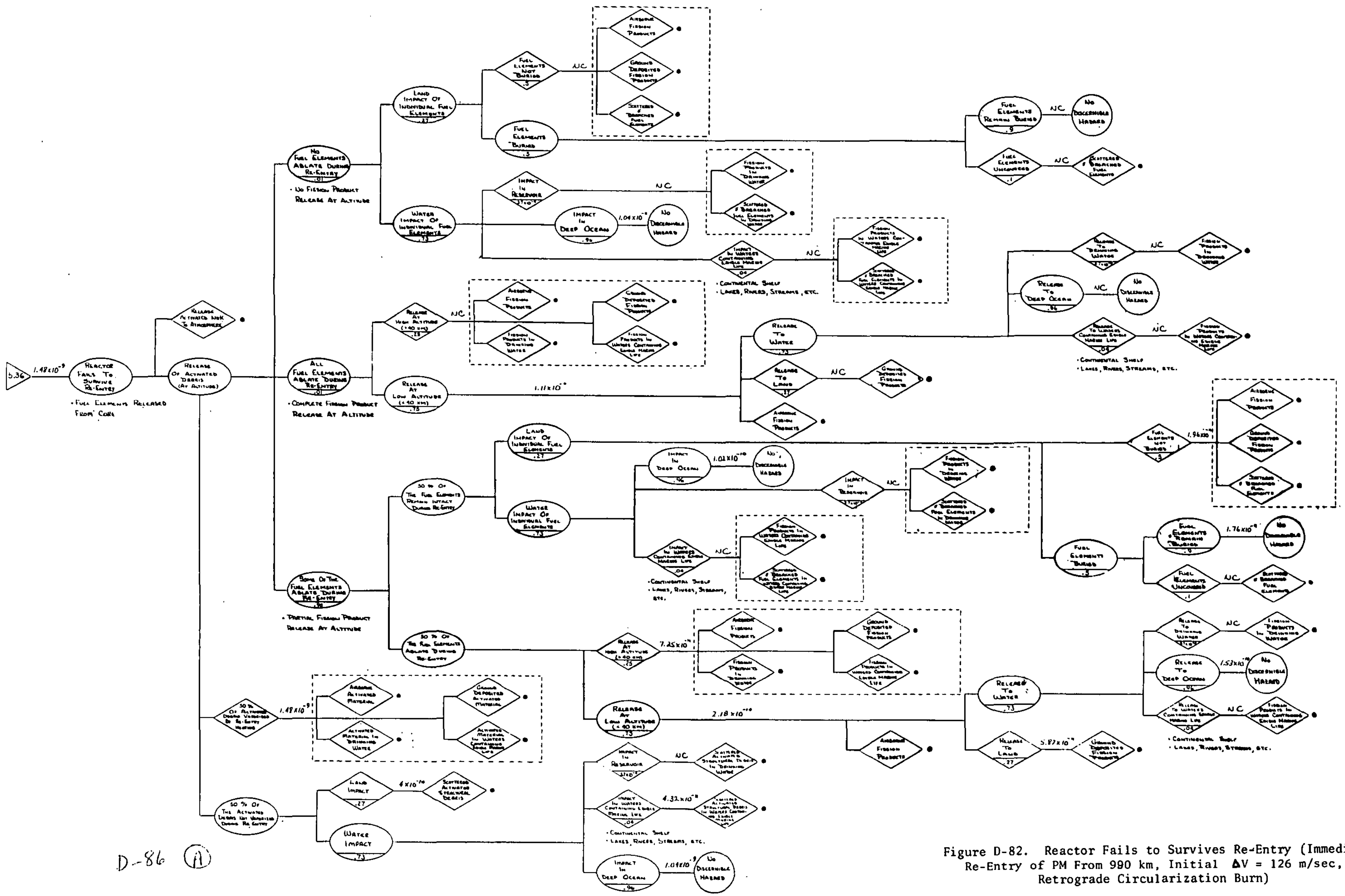
(B)



D-85 (A)

Figure D-81. Intact Reactor Survives Re-Entry (Immediate Re-Entry of PM From 990 km, Initial ΔV = 126 m/sec, Retrograde Circularization Burn)

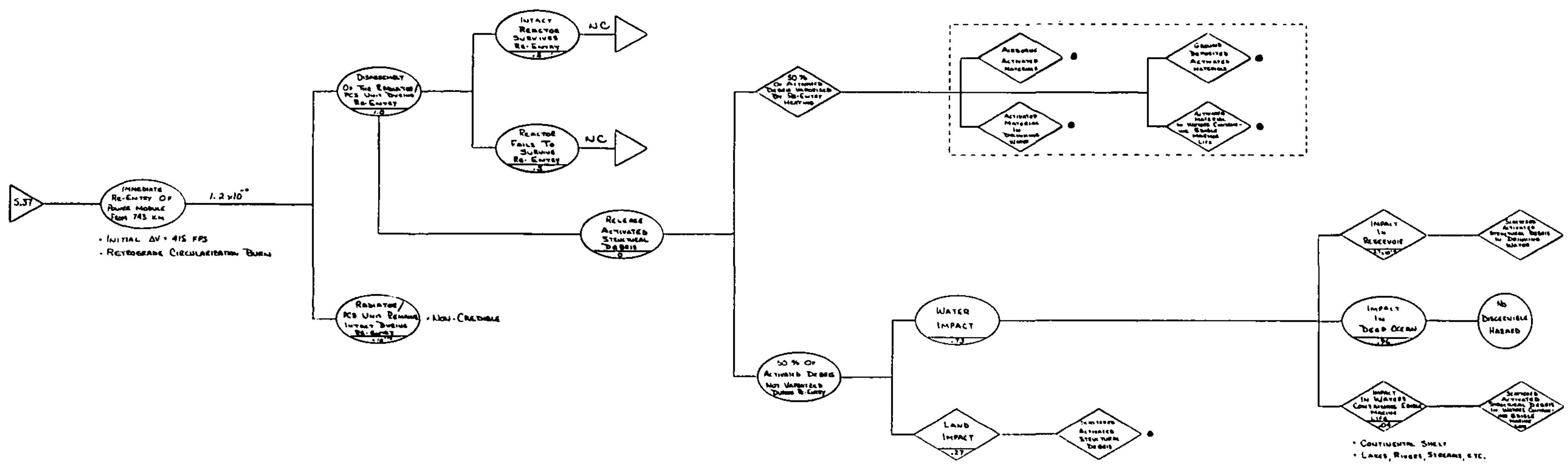
(B)



D-86 (A)

Figure D-82. Reactor Fails to Survives Re-Entry (Immediate Re-Entry of PM From 990 km, Initial ΔV = 126 m/sec, Retrograde Circularization Burn)

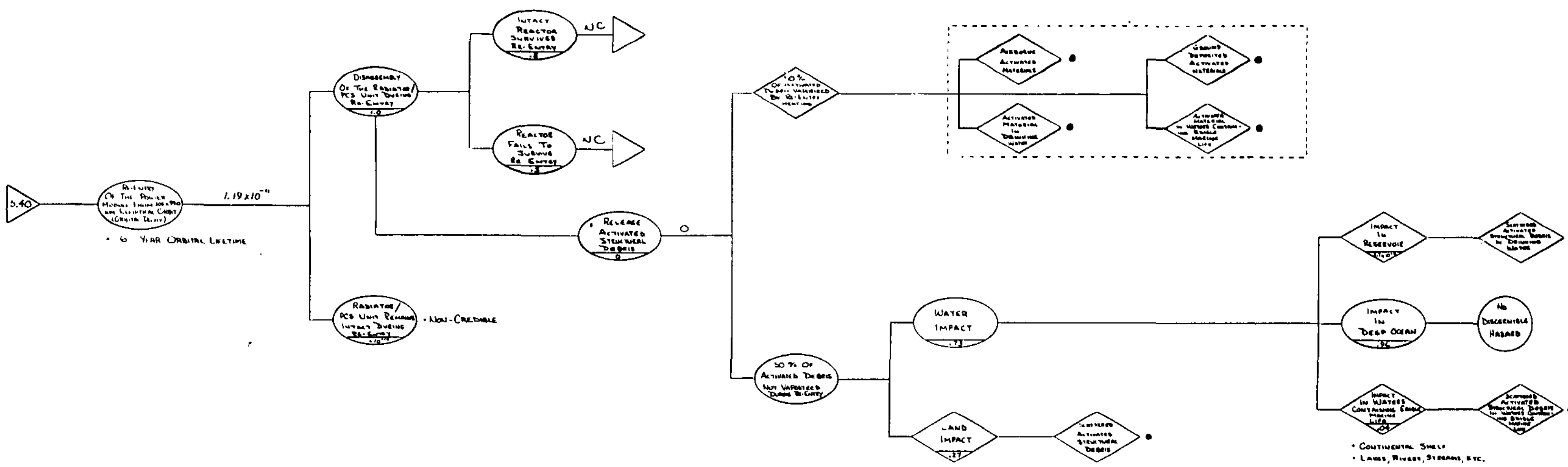
(B)



D-87 (A)

Figure D-83. Immediate Re-Entry of PM From 743 km, Initial ΔV = 126 m/sec (Retrograde Circularization Burn)

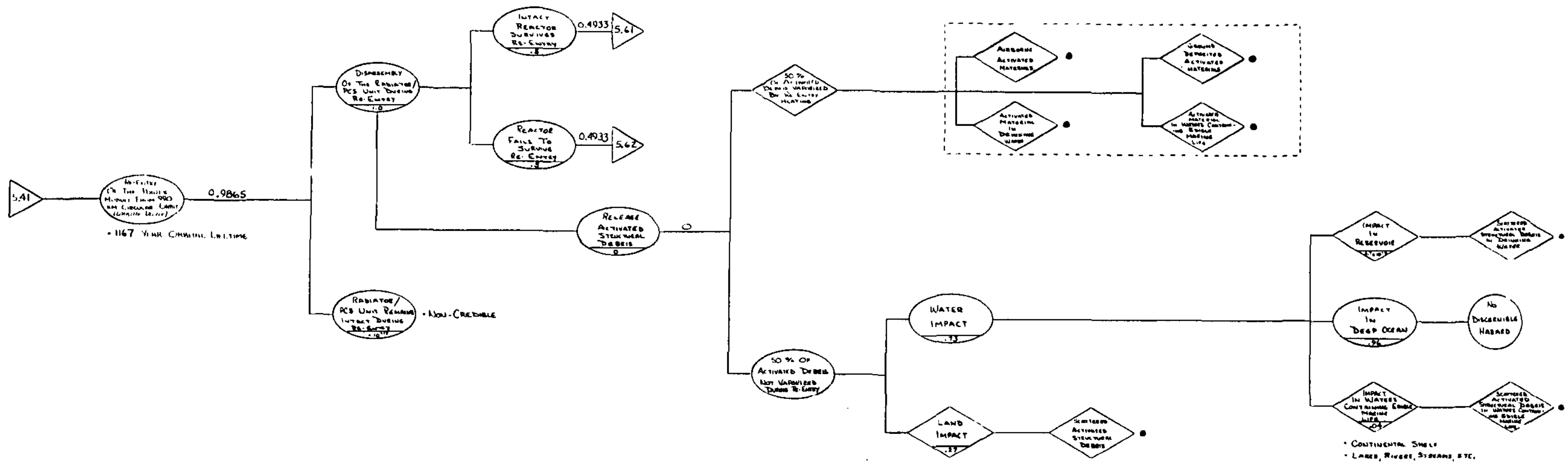
(B)



D-88 (A)

Figure D-84. Re-Entry of PM From 305 x 990 km Elliptical Orbit (Orbital Decay)

(B)



D-89- (A)

Figure D-85. Re-Entry of PM From 990 km Circular Orbit
(Orbital Decay)

(B)

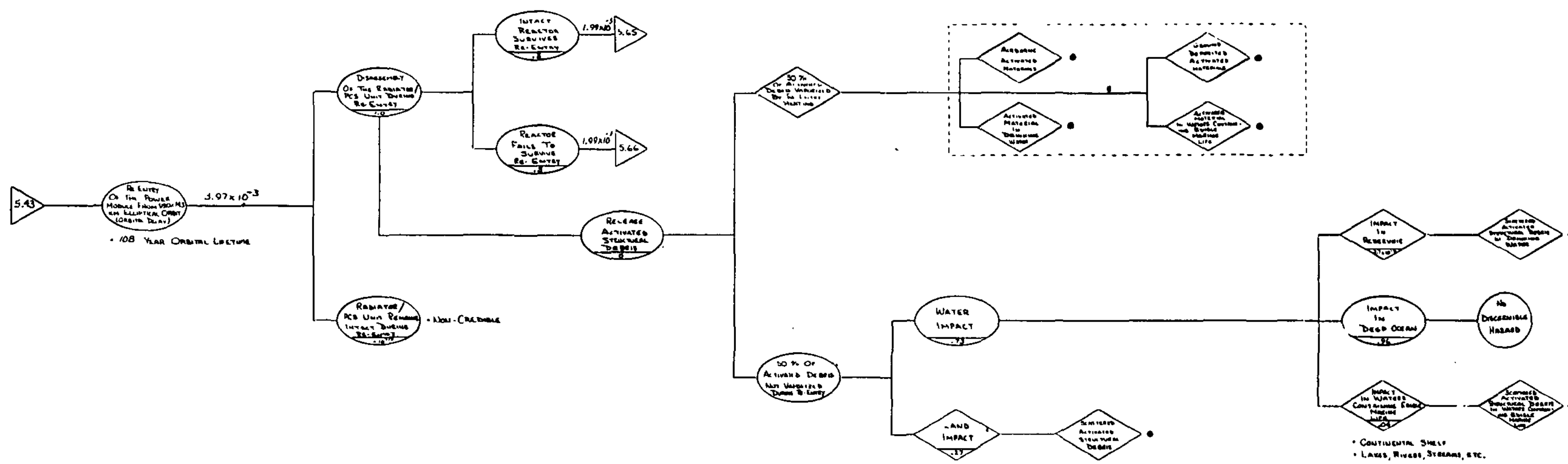
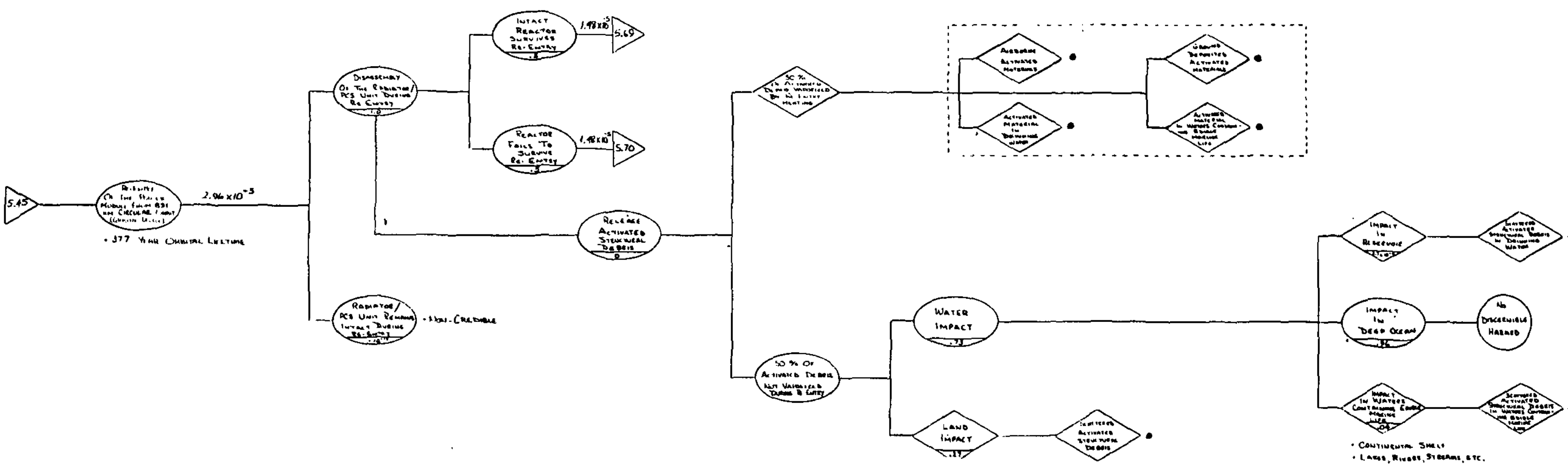


Figure D-86. Re-Entry of PM From 990 x 743 km Elliptical Orbit (Orbital Decay)

D-90 (A)

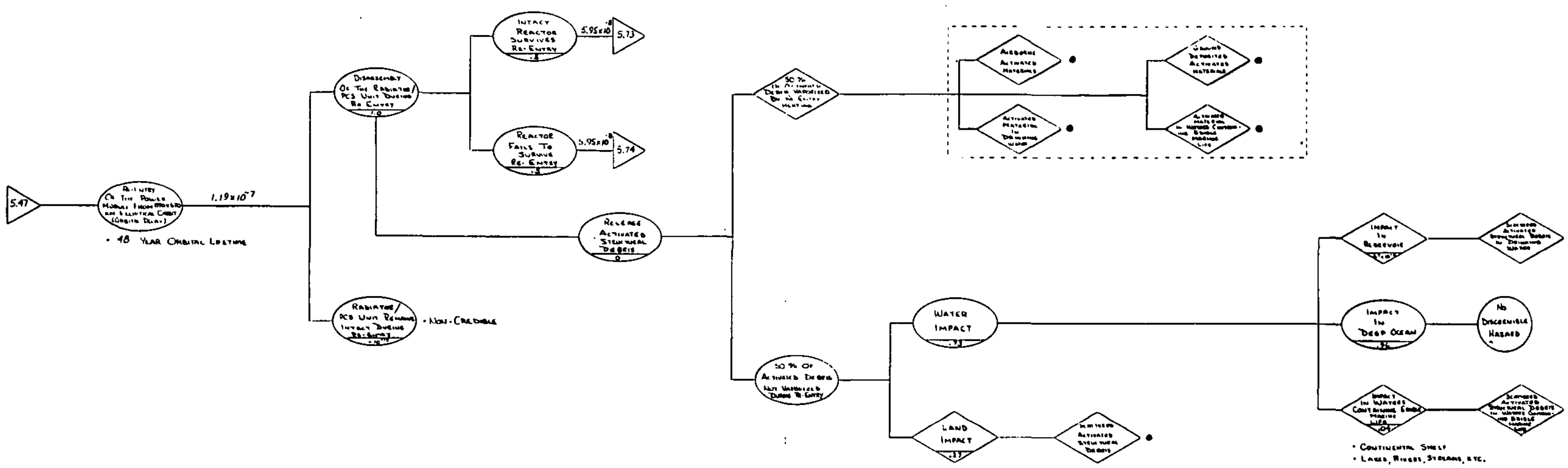
 (B)



D-91 (A)

Figure D-87. Re-Entry of PM From 891 km Circular Orbit (Orbital Decay)

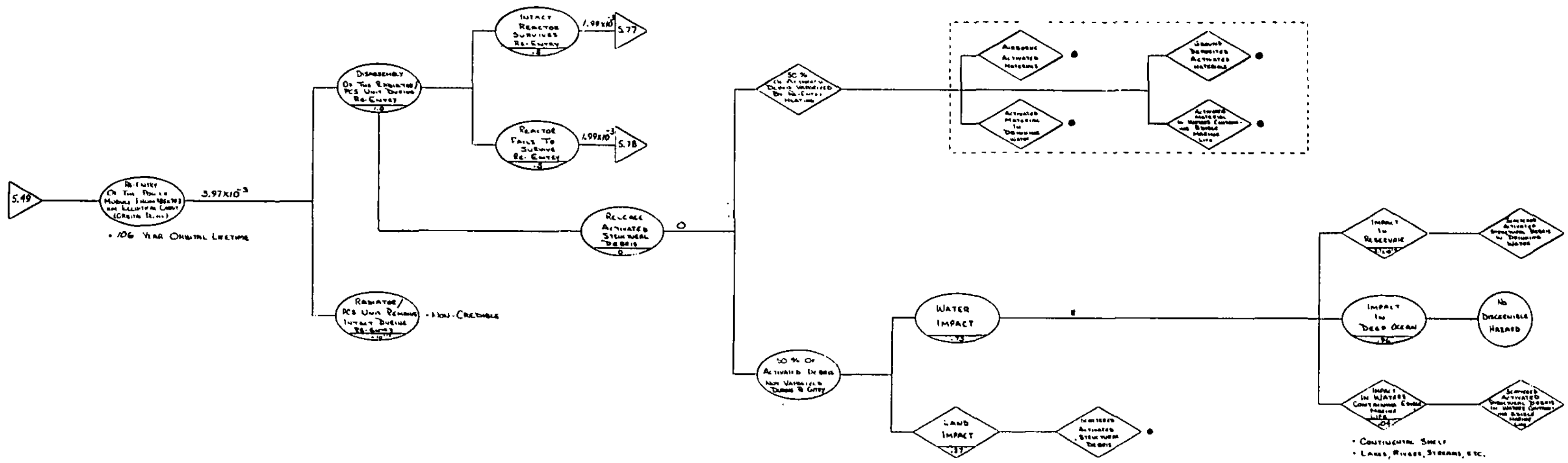
(B)



D-92 (A)

Figure D-88. Re-Entry of PM From 890 x 670 km Elliptical Orbit (Orbital Decay)

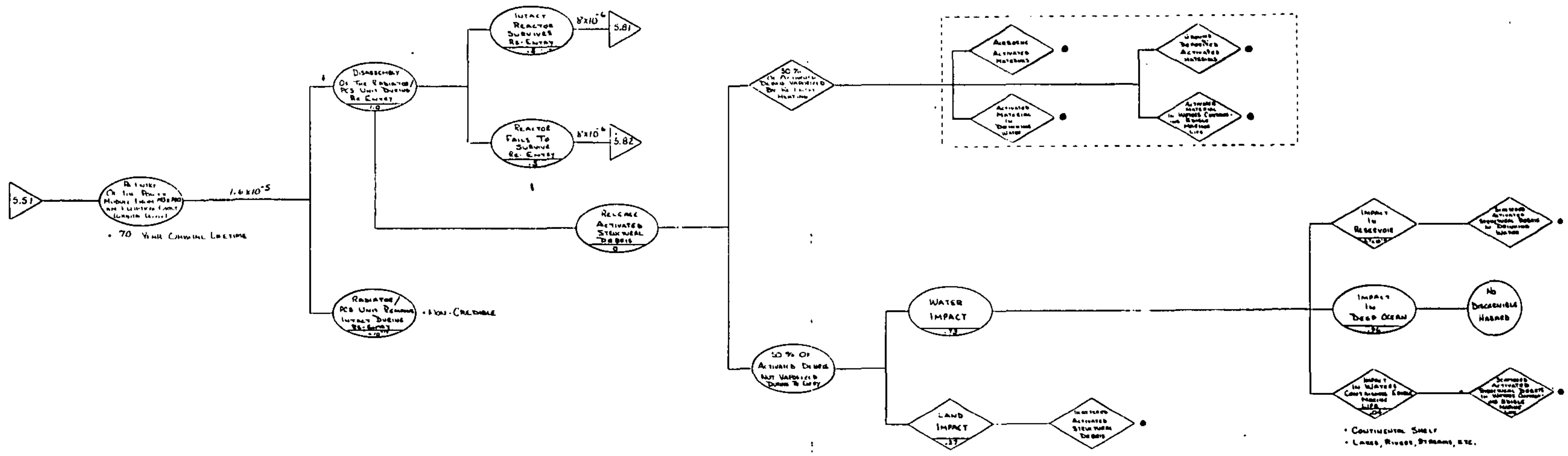
(B)



D-93 (A)

Figure D-89. Re-Entry of PM From 985 x 743 km Elliptical Orbit (Orbital Decay)

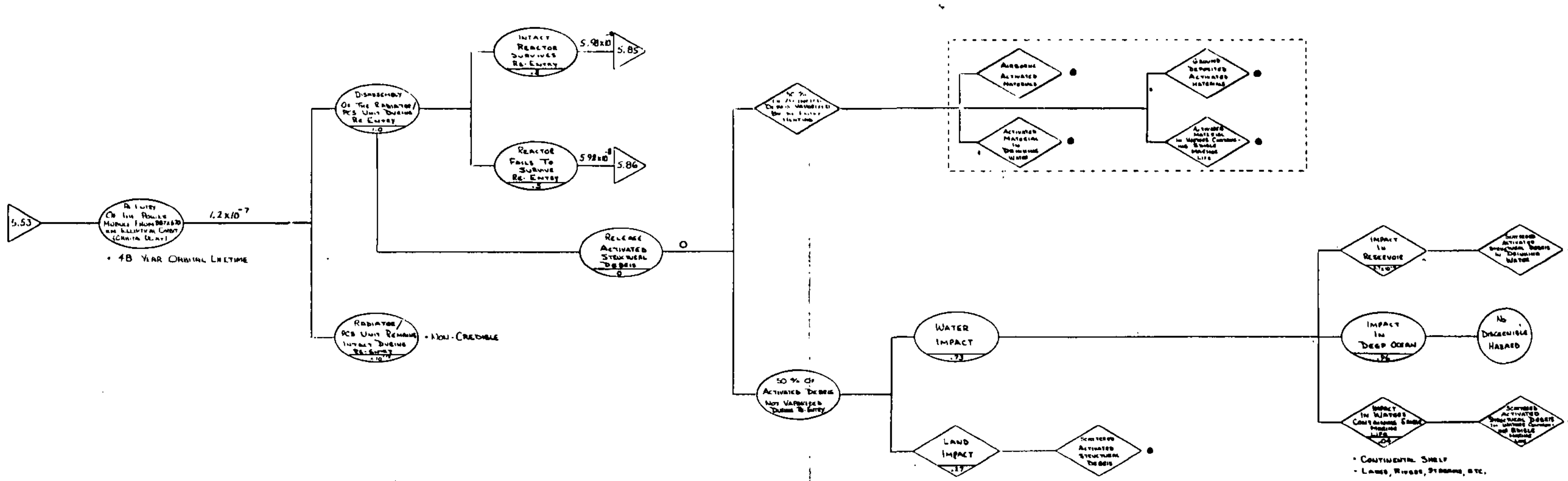
(B)



D-94 (A)

Figure D-90. Re-Entry of PM From 743 x 740 km Elliptical Orbit (Orbital Decay)

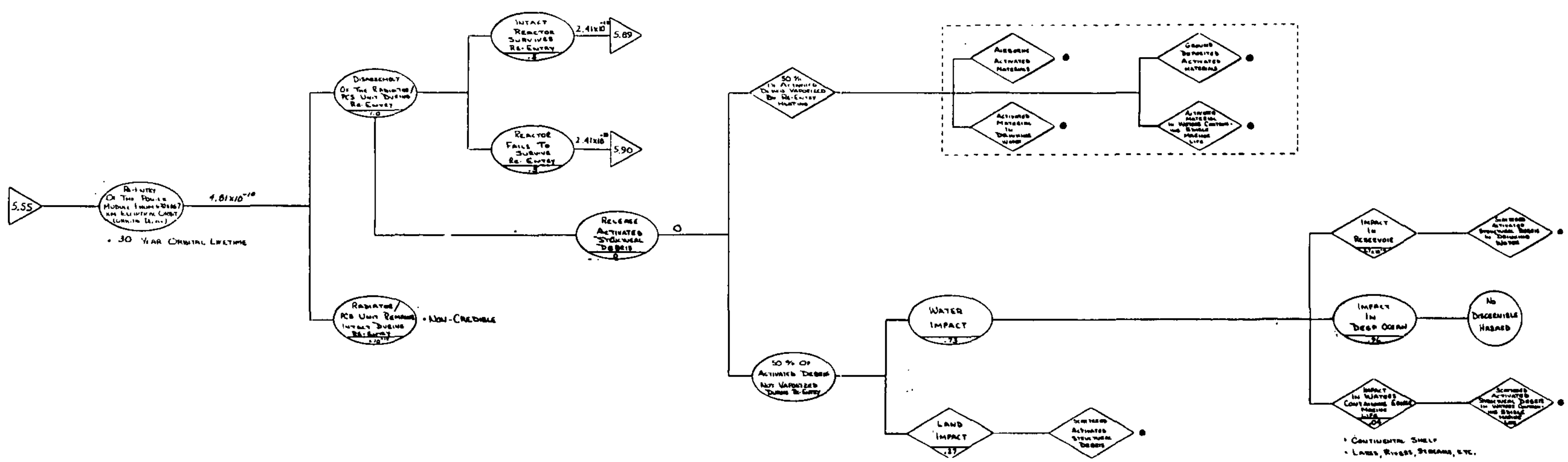
(B)



D-95 Ⓐ

Figure D-91. Re-Entry of PM From 887 x 670 km Elliptical Orbit (Orbital Decay)

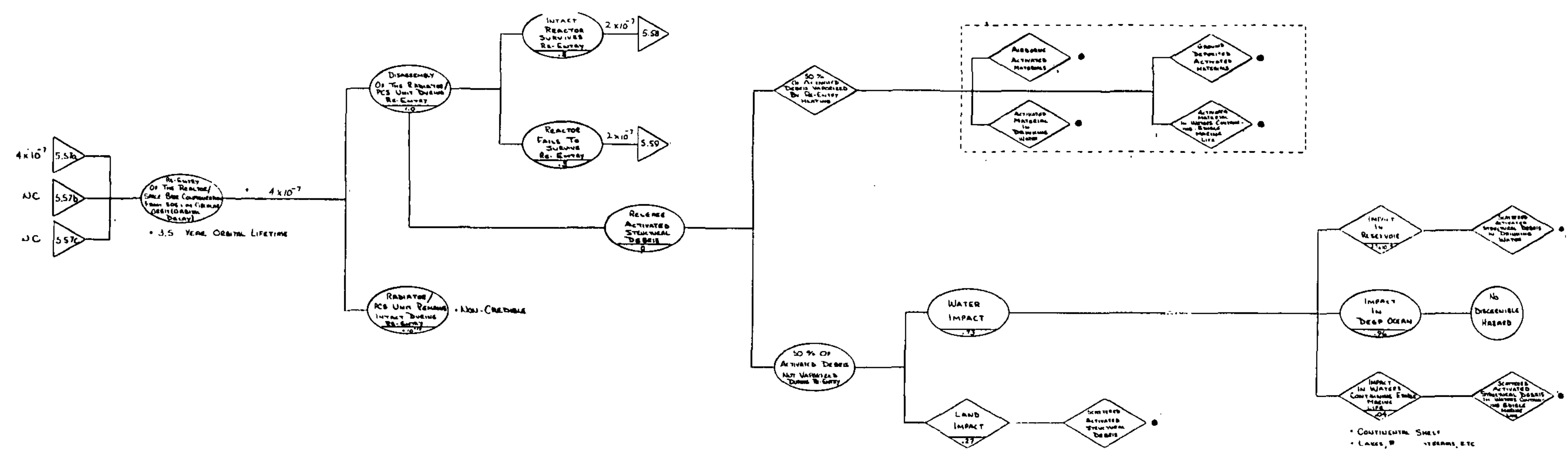
Ⓑ



D-96 Ⓐ

Figure D-92. Re-Entry of PM From 670 x 667 km Elliptical Orbit (Orbital Decay)

Ⓑ



D-97 (A)

Figure D-93. Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit (Orbital Decay)

(B)

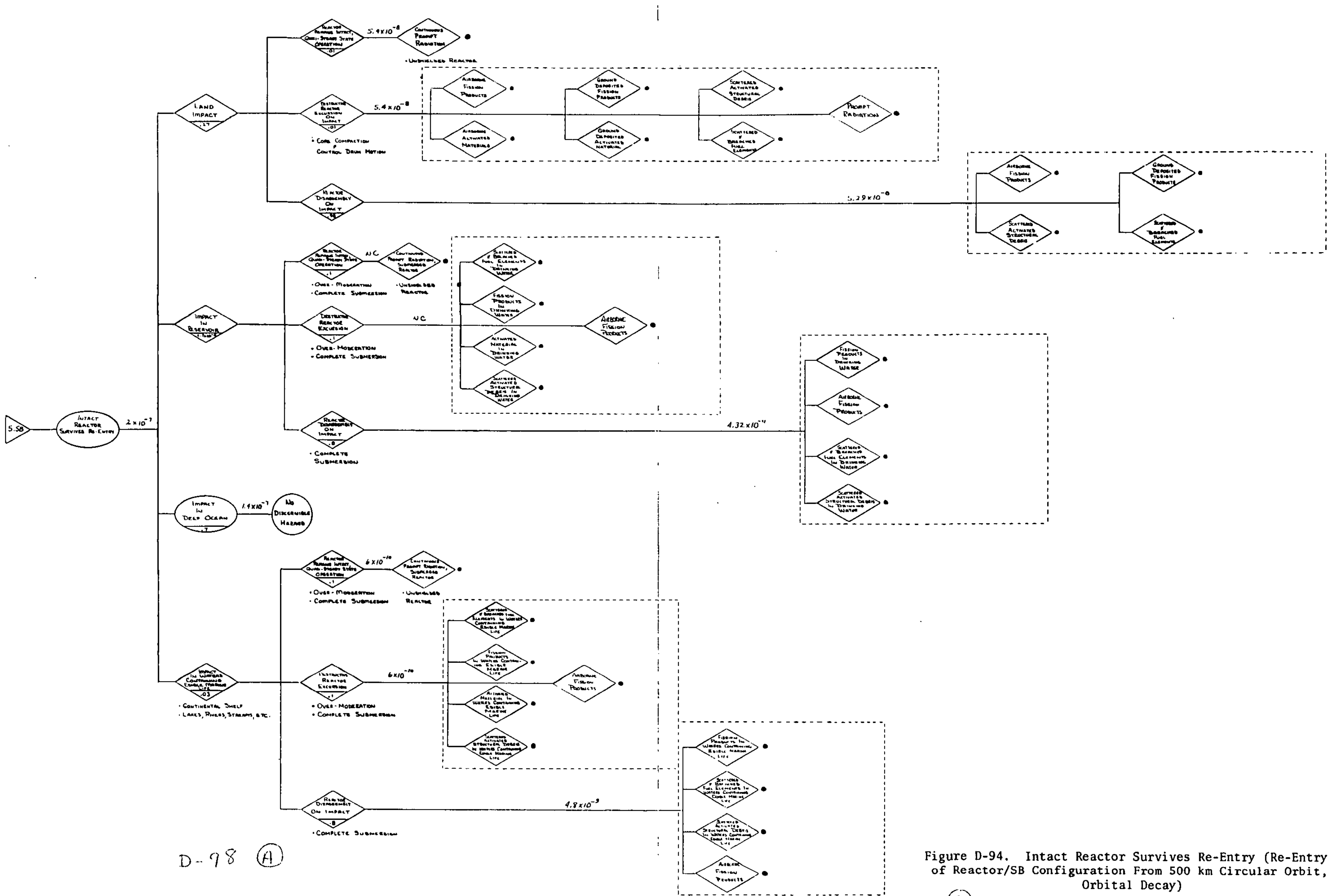


Figure D-94. Intact Reactor Survives Re-Entry (Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay)

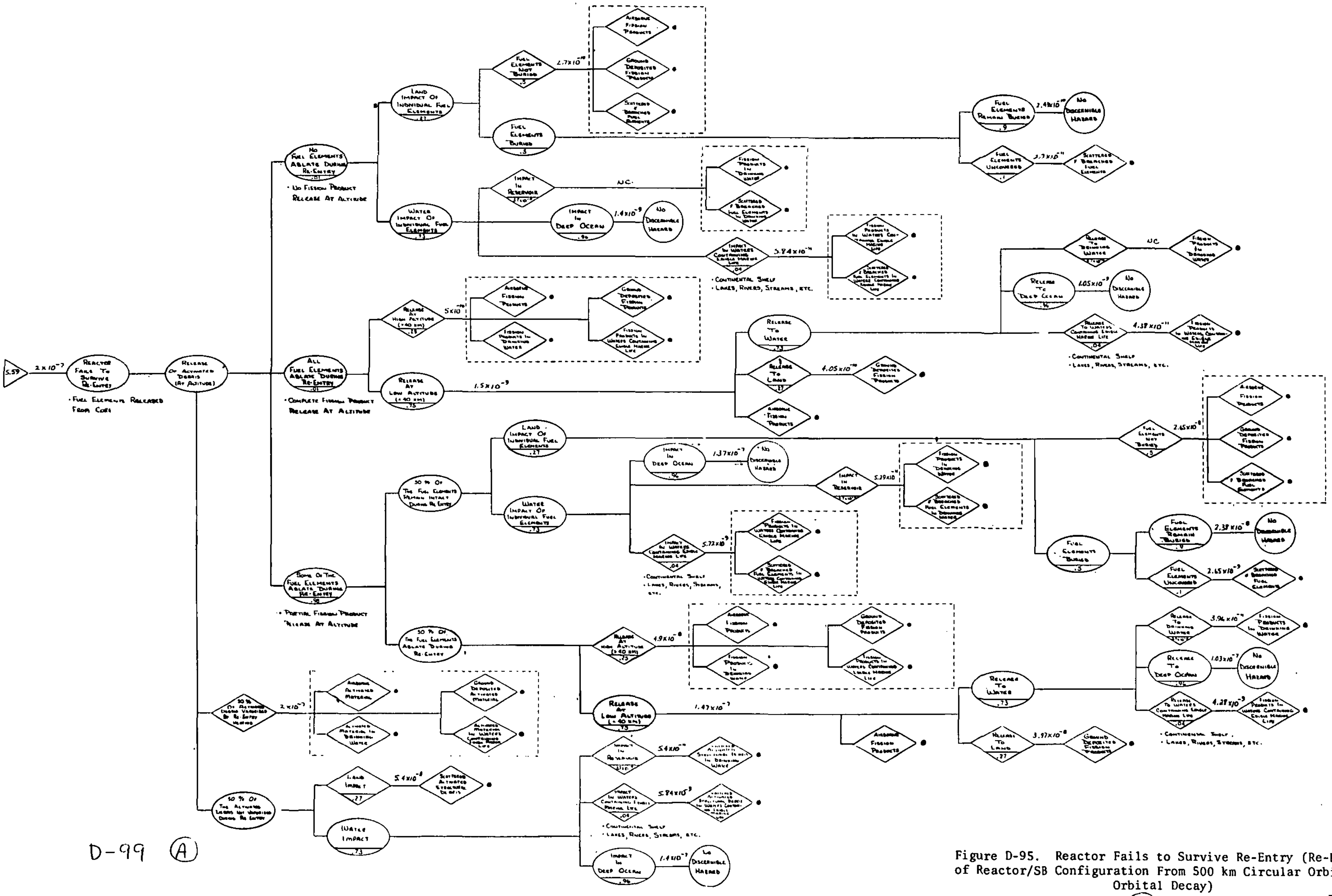
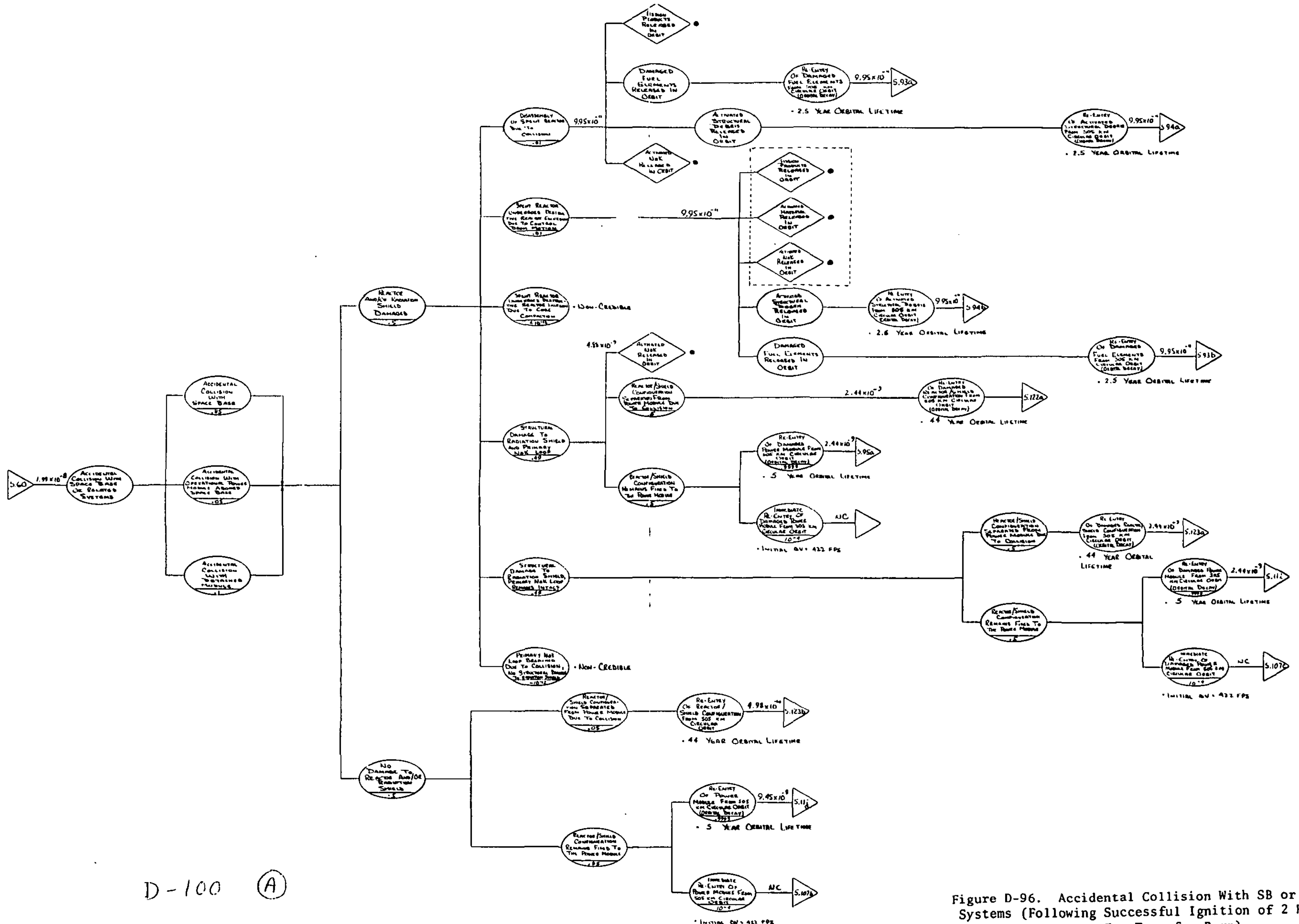


Figure D-95. Reactor Fails to Survive Re-Entry (Re-Entry of Reactor/SB Configuration From 500 km Circular Orbit, Orbital Decay)

D-99 (A) (B)



D-100 (A)

Figure D-96. Accidental Collision With SB or Related Systems (Following Successful Ignition of 2 Rockets For Transfer Burn)

(B)

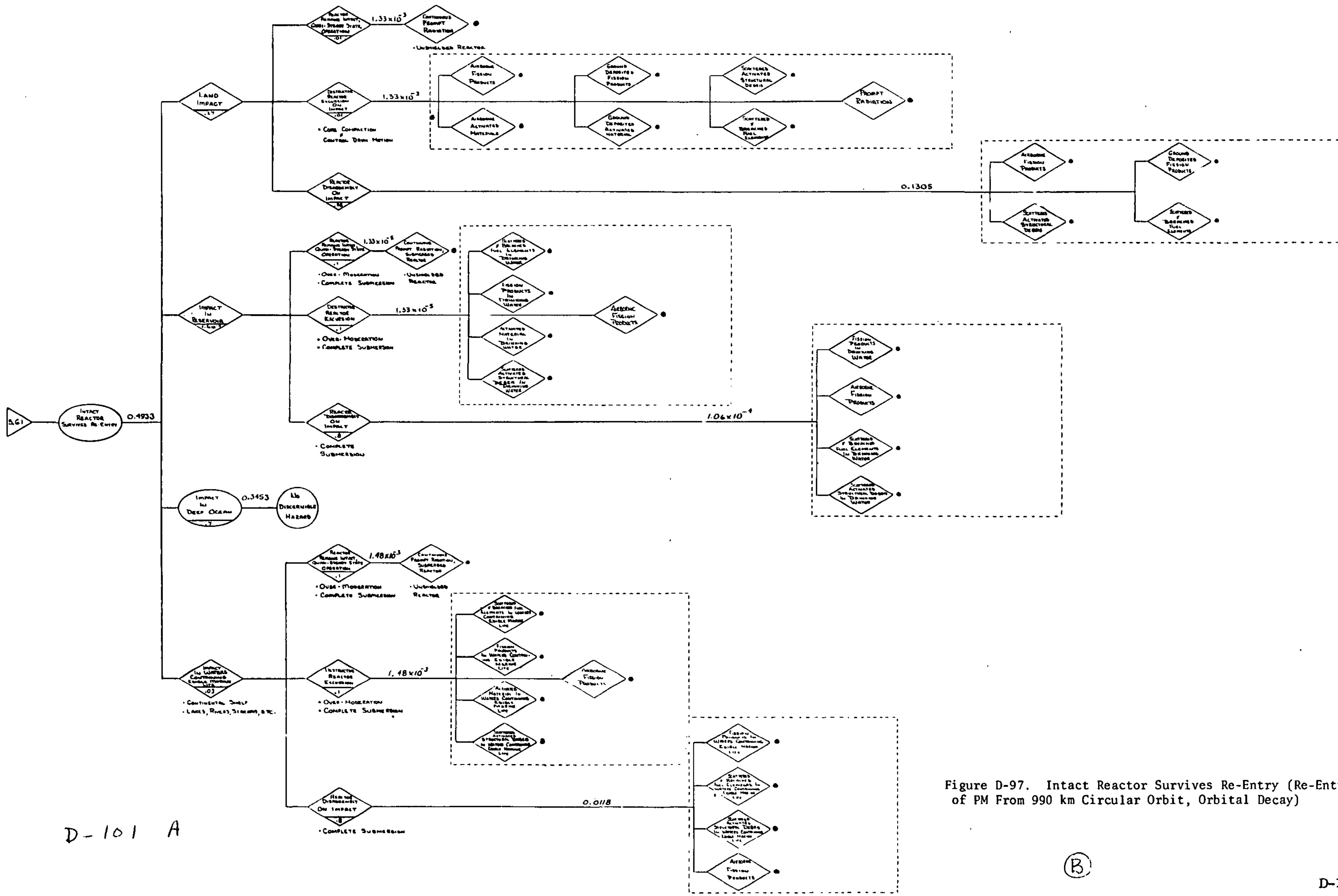
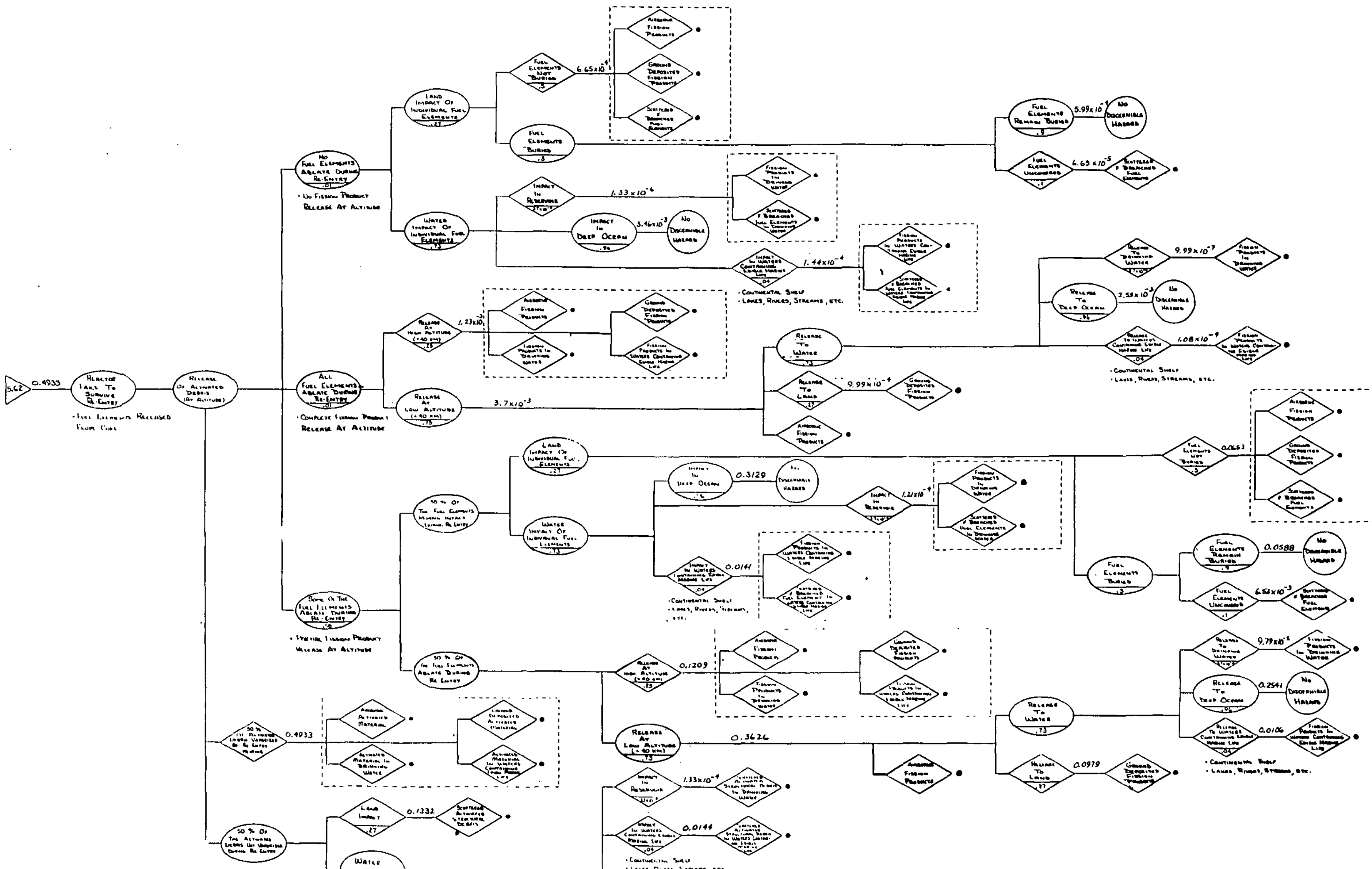


Figure D-97. Intact Reactor Survives Re-Entry (Re-Entry of PM From 990 km Circular Orbit, Orbital Decay)

D-101 A

B



D-102 (A)

Figure D-98. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 990 km Circular Orbit, Orbital Decay)

(B)

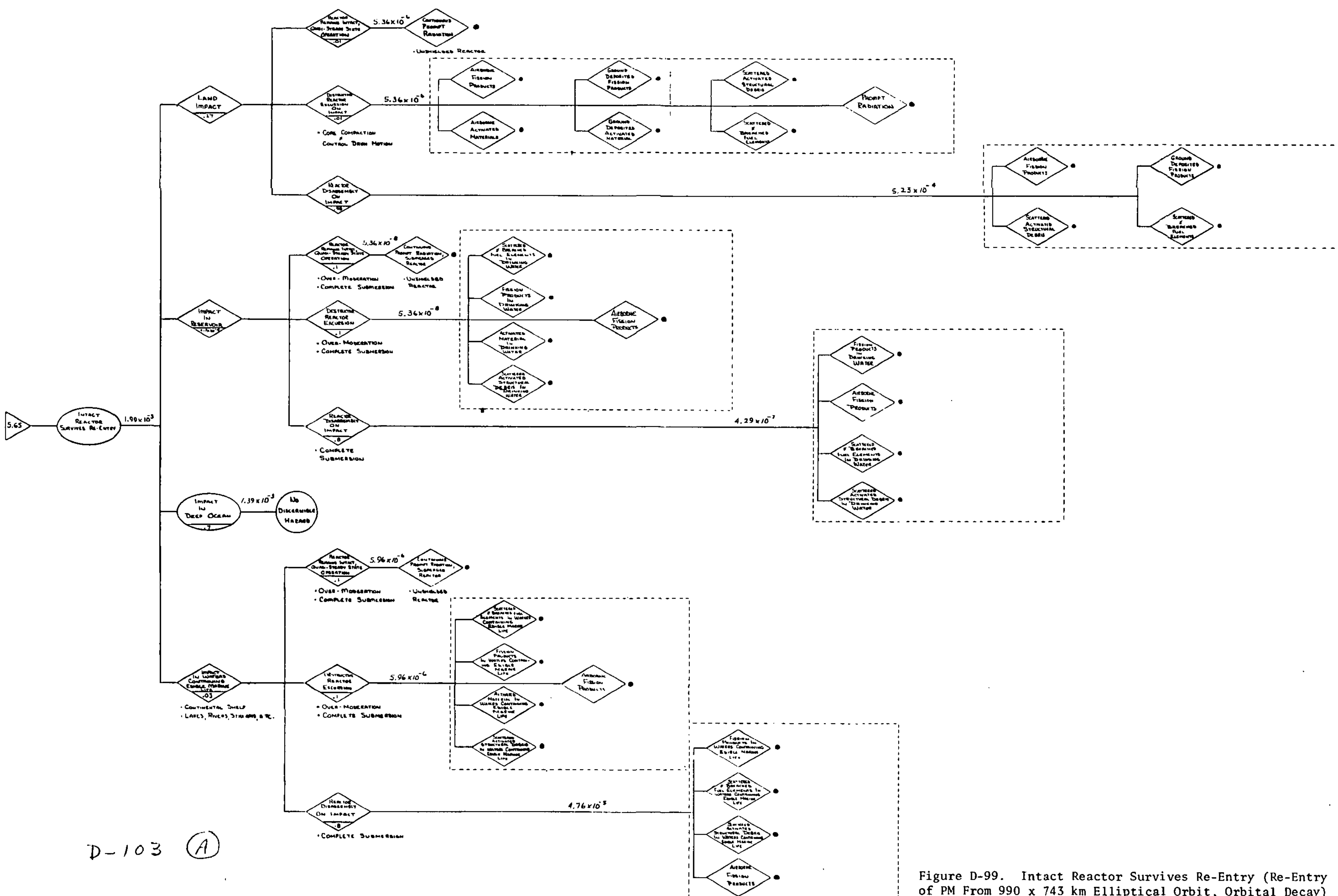


Figure D-99. Intact Reactor Survives Re-Entry (Re-Entry of PM From 990 x 743 km Elliptical Orbit, Orbital Decay)

D-104 (A)

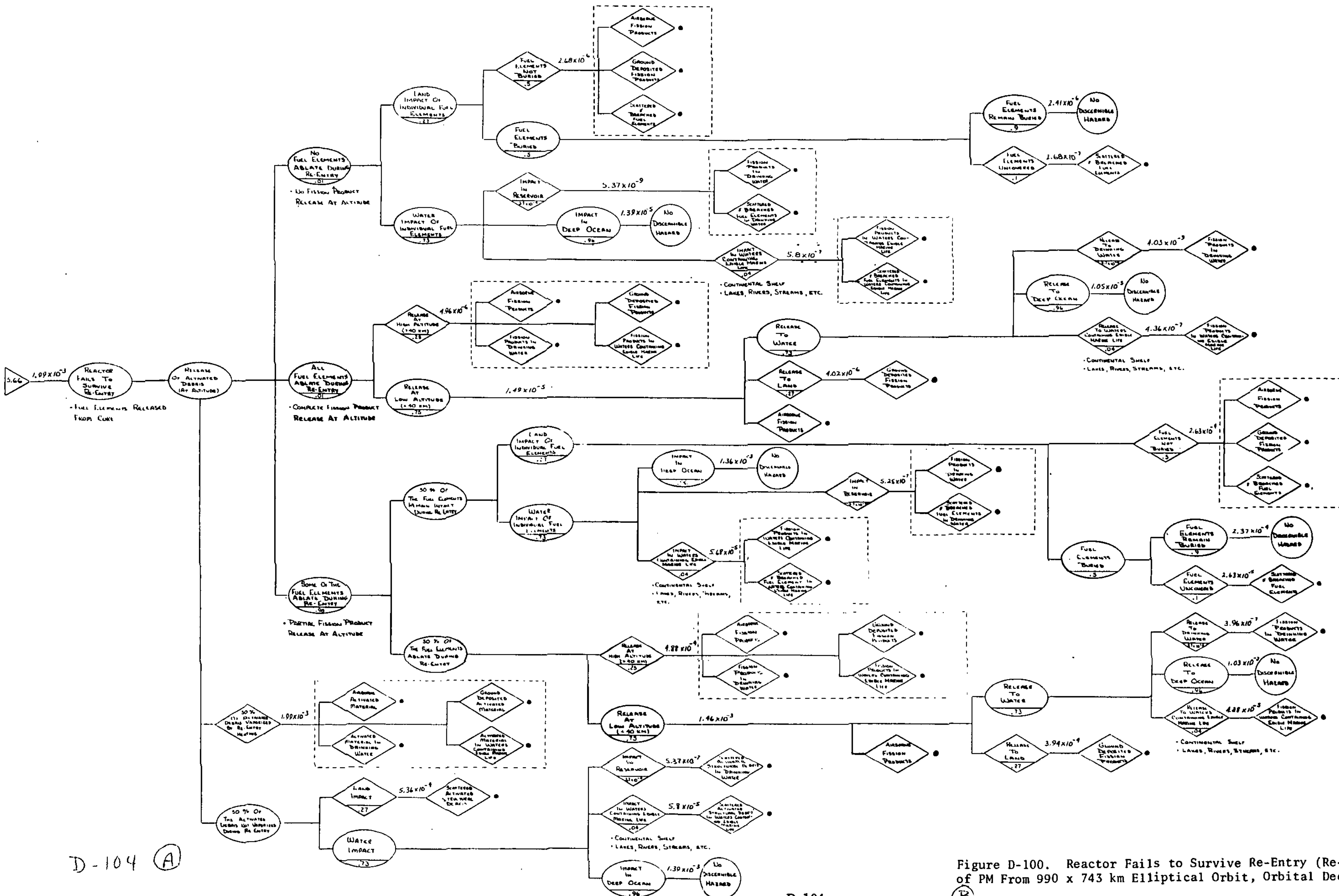


Figure D-100. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 990 x 743 km Elliptical Orbit, Orbital Decay) (B)

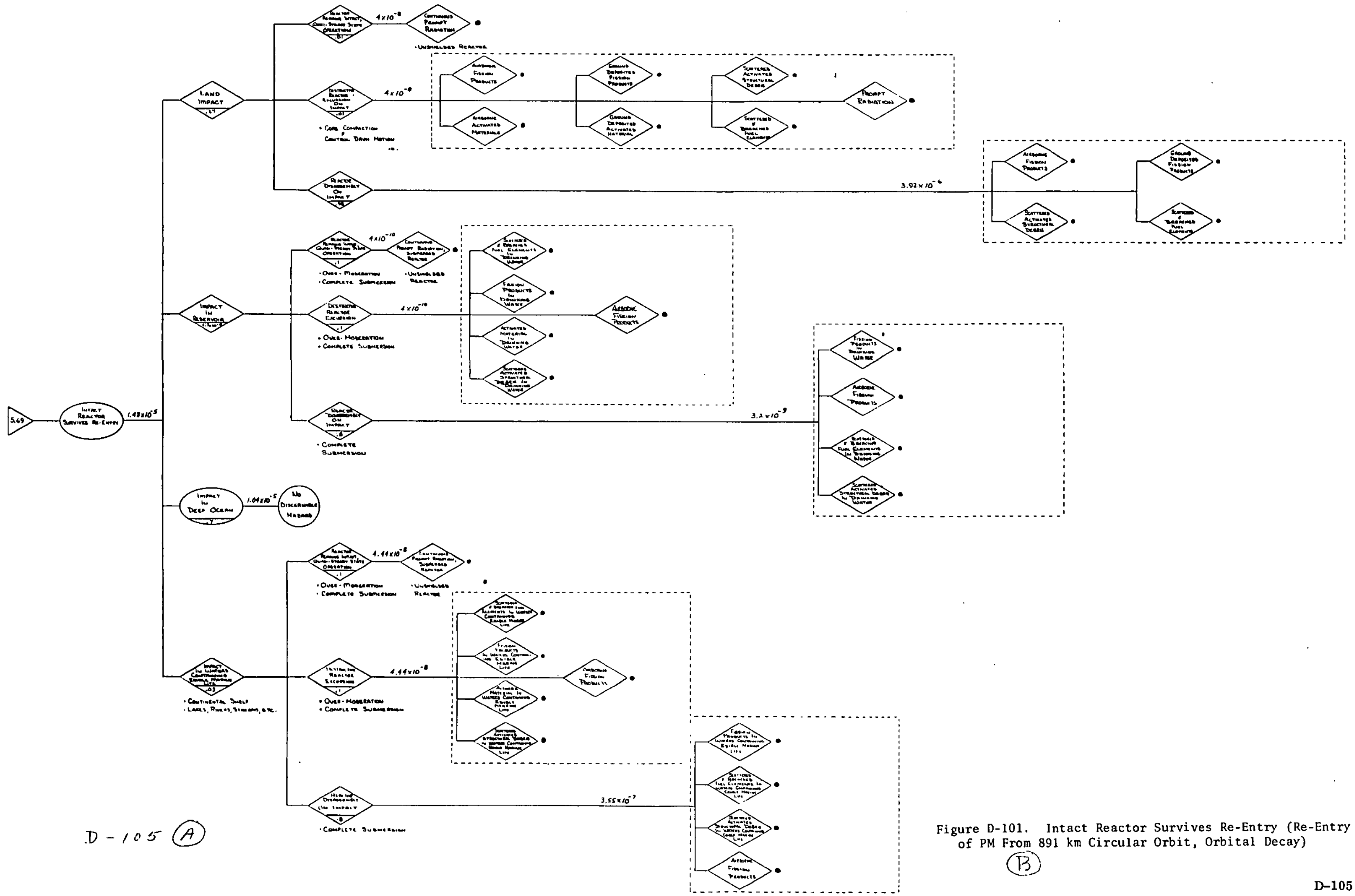
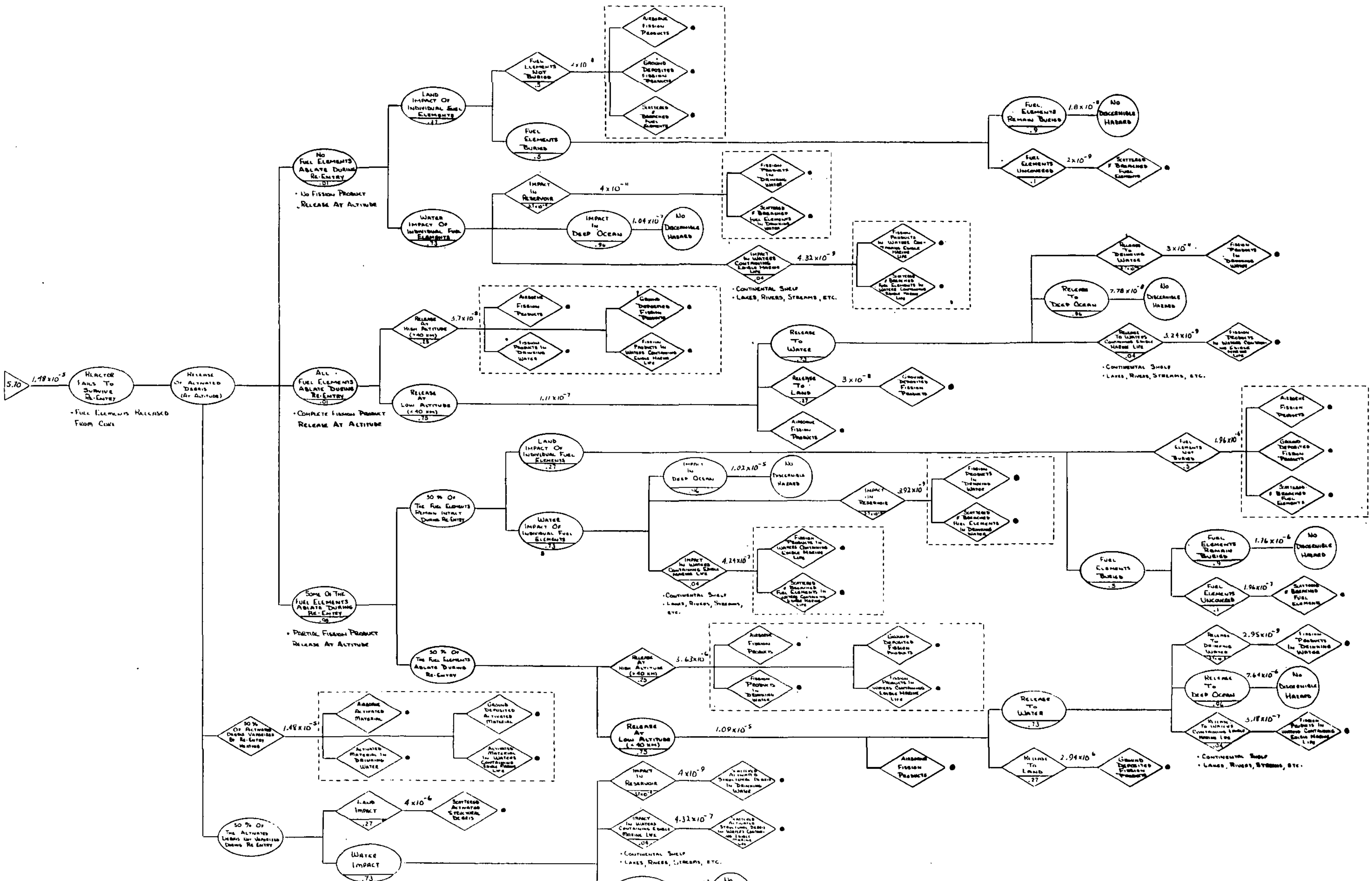
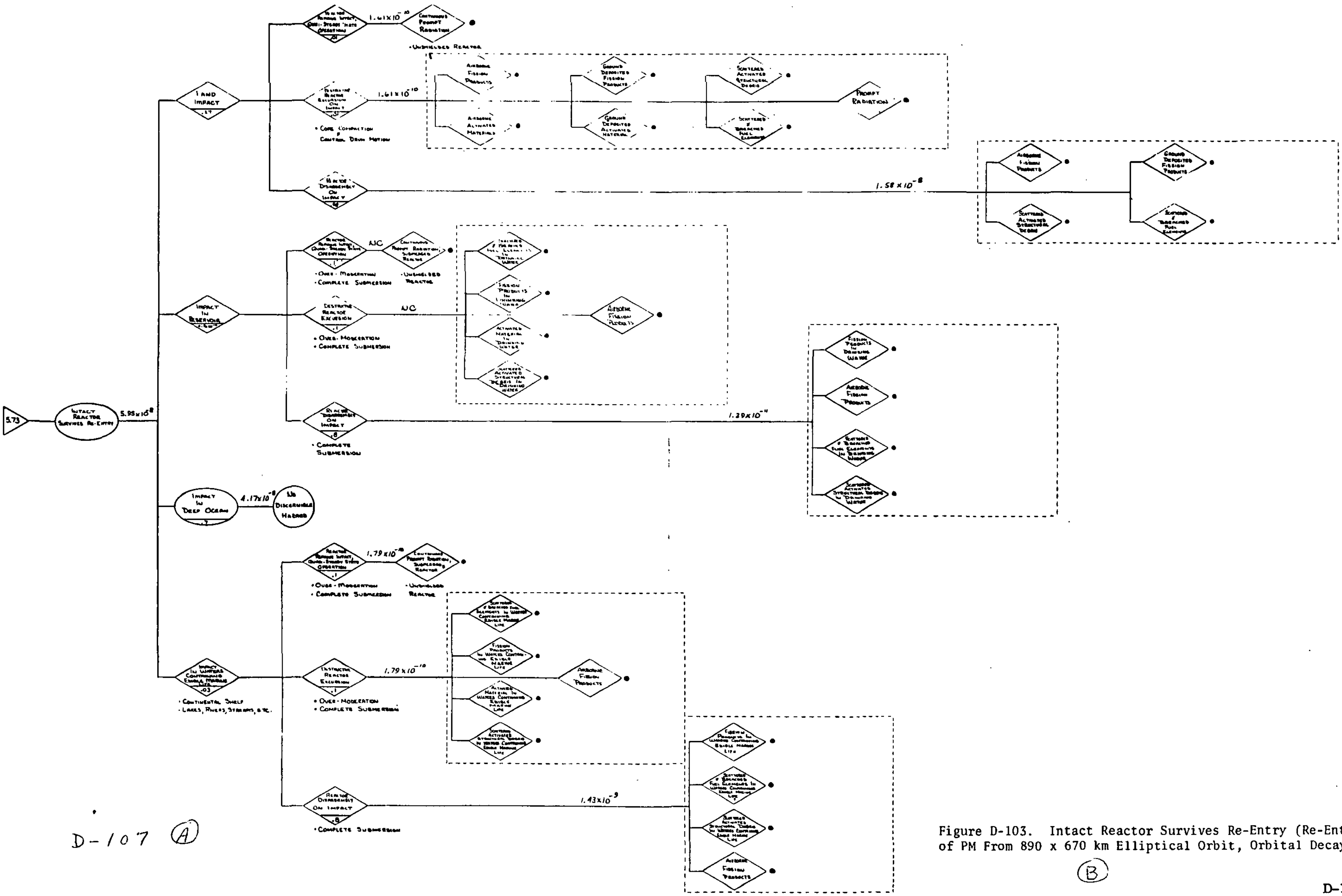


Figure D-101. Intact Reactor Survives Re-Entry (Re-Entry of PM From 891 km Circular Orbit, Orbital Decay)



D · 106 (A)

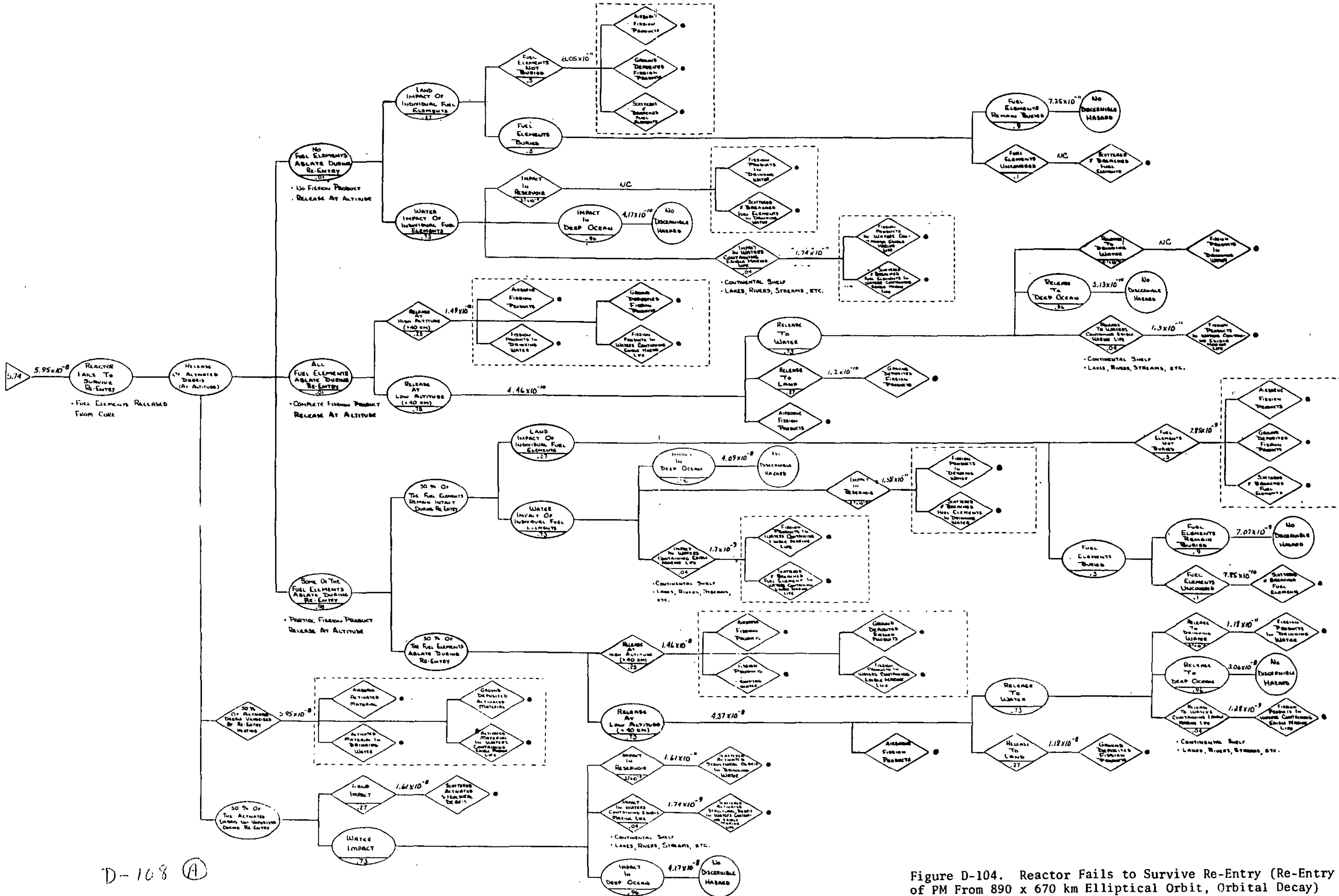
Figure D-102. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 891 km Circular Orbit, Orbital Decay)
(B)



D-107 (A)

Figure D-103. Intact Reactor Survives Re-Entry (Re-Entry of PM From 890 x 670 km Elliptical Orbit, Orbital Decay)

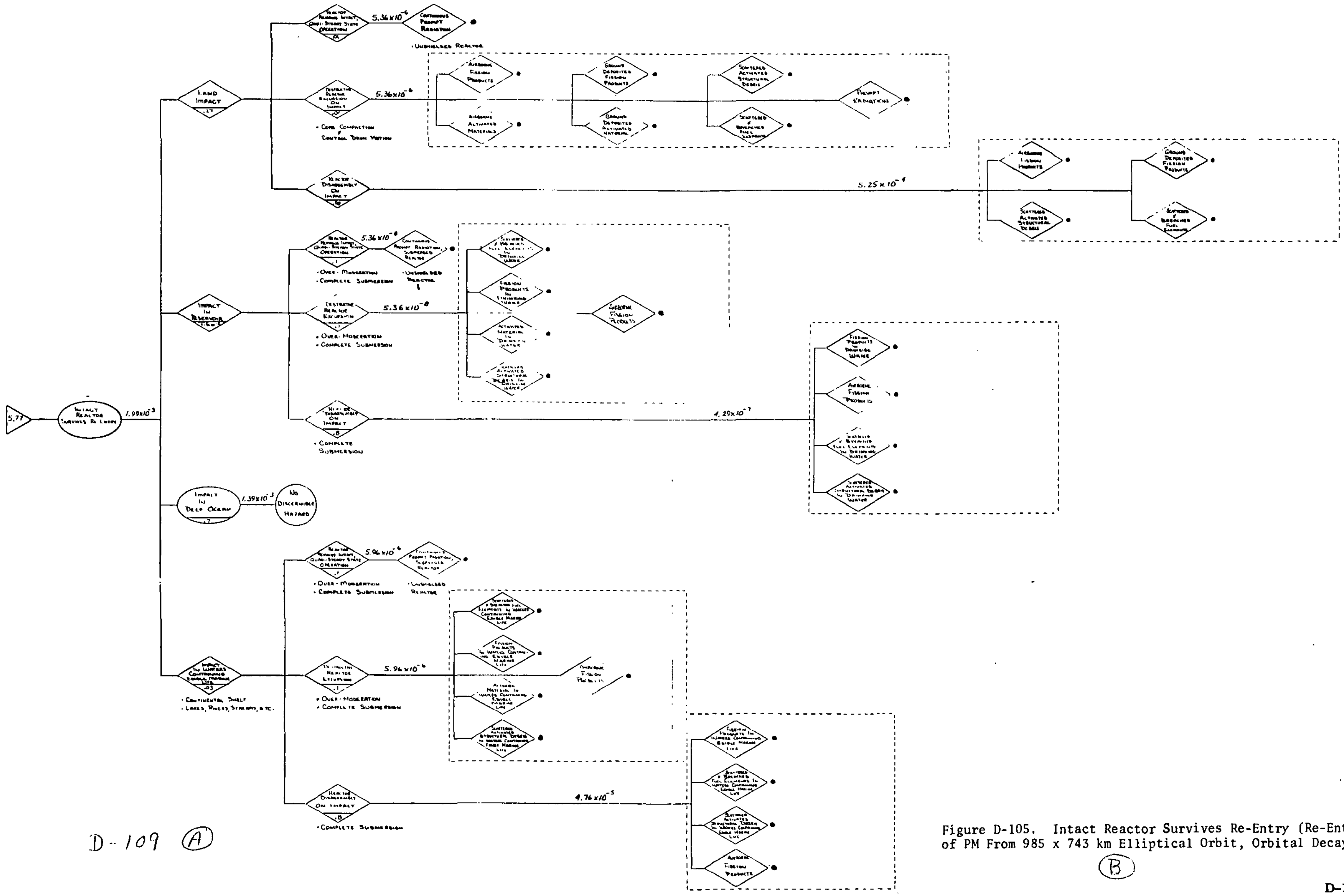
(B)



D-108 (A)

Figure D-104. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 890 x 670 km Elliptical Orbit, Orbital Decay)

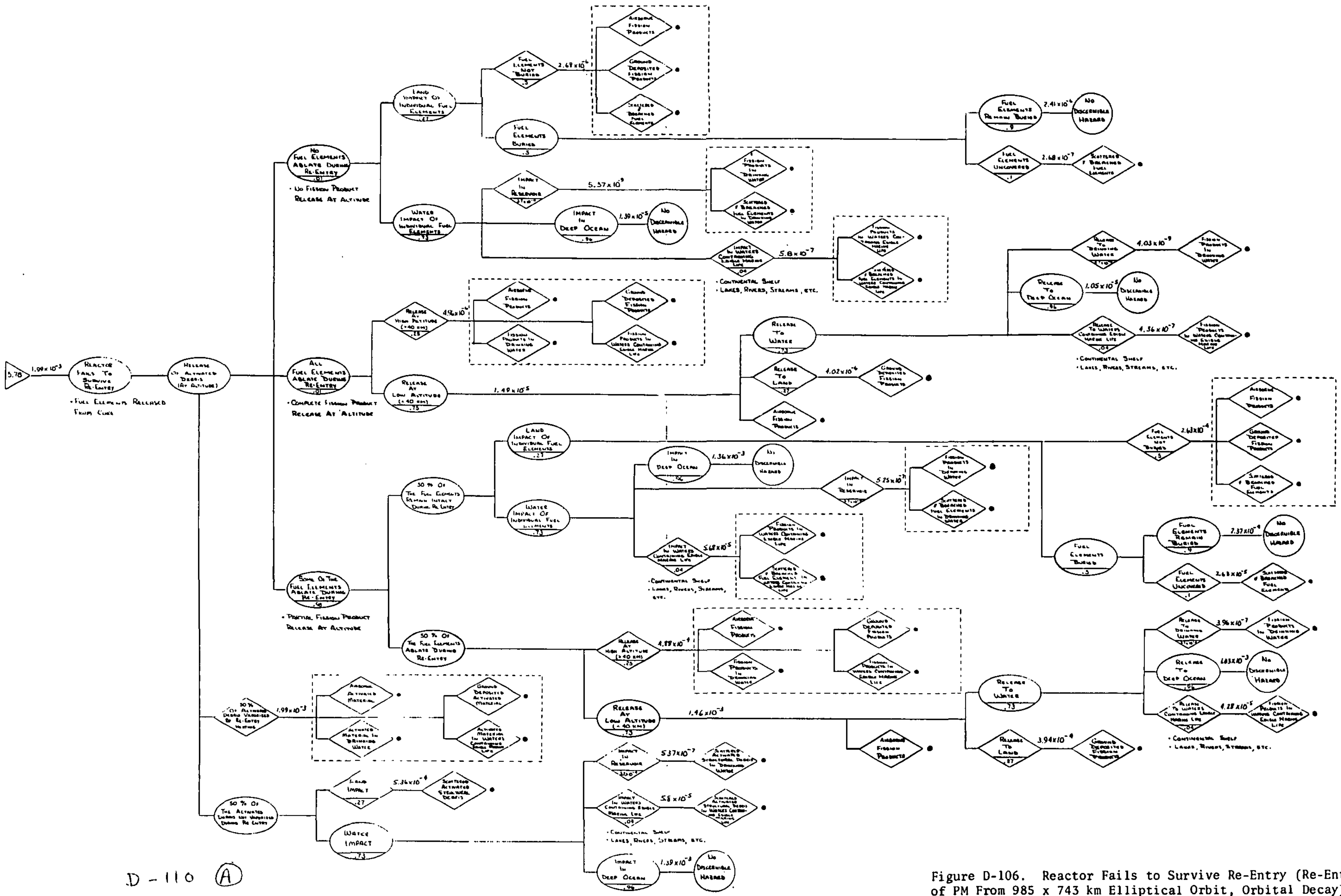
(B)



D-109 (A)

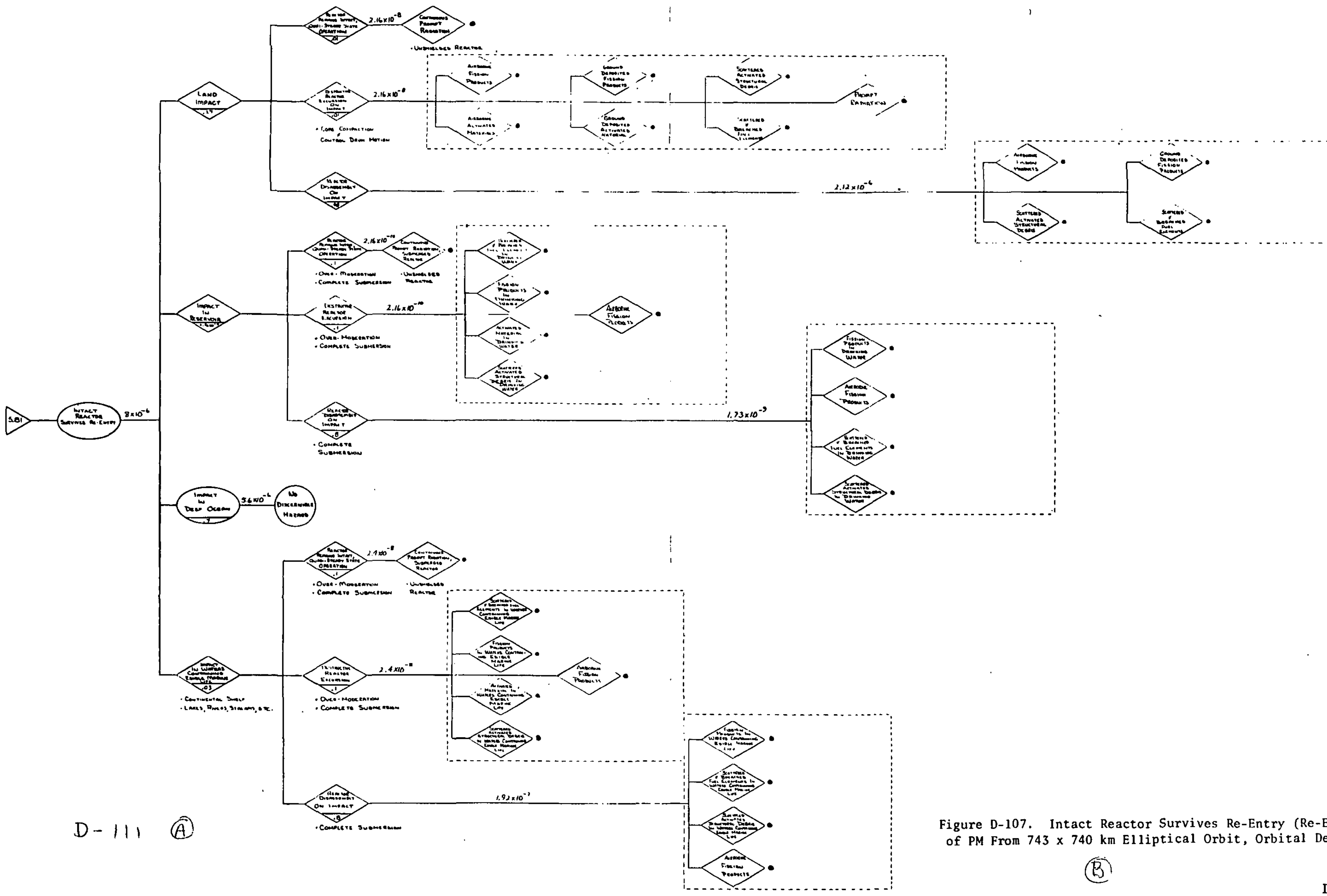
Figure D-105. Intact Reactor Survives Re-Entry (Re-Entry of PM From 985 x 743 km Elliptical Orbit, Orbital Decay)

(B)



D-110 (A)

Figure D-106. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 985 x 743 km Elliptical Orbit, Orbital Decay) (B)



D-111 Ⓐ

Figure D-107. Intact Reactor Survives Re-Entry (Re-Entry of PM From 743 x 740 km Elliptical Orbit, Orbital Decay)

Ⓑ

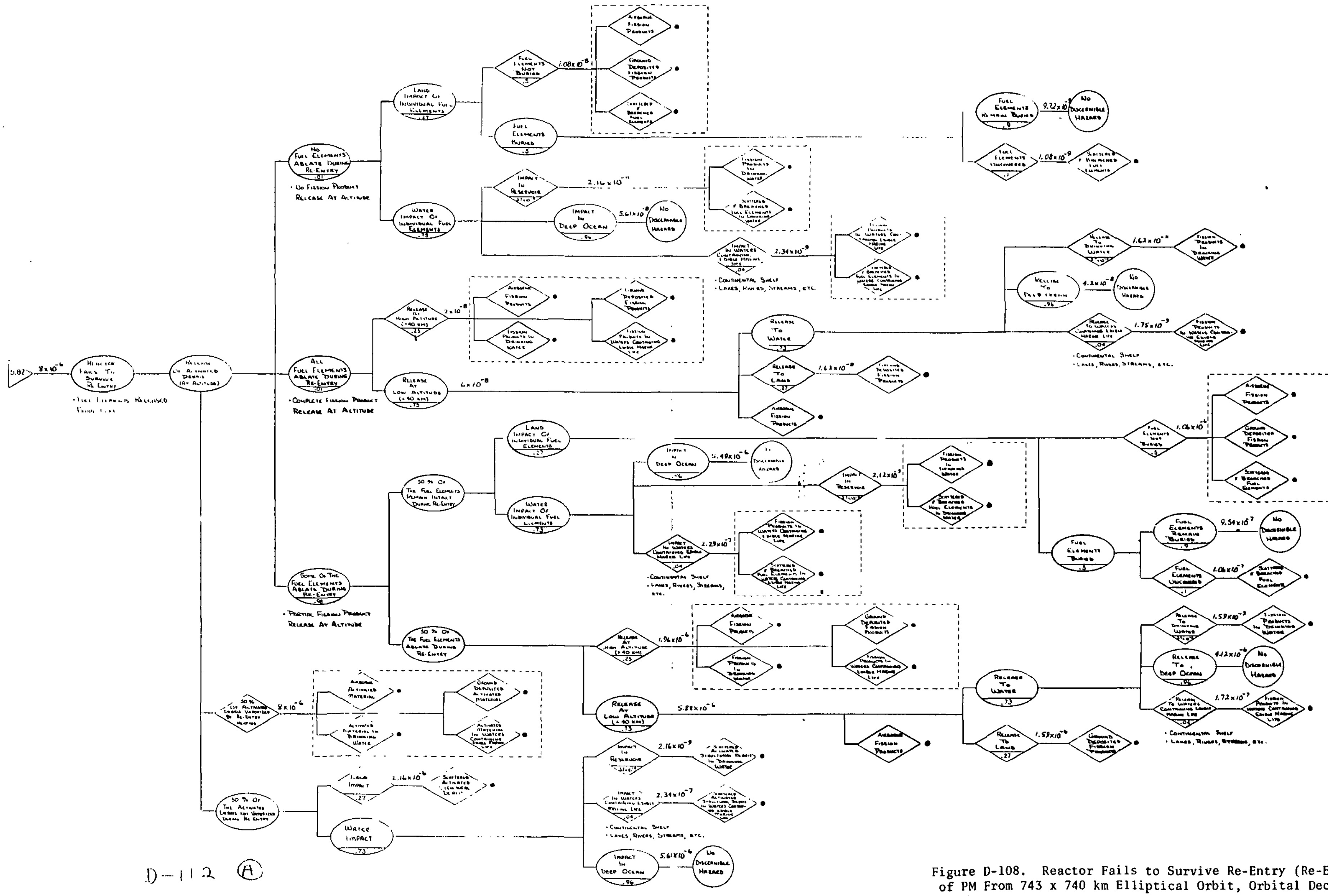


Figure D-108. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 743 x 740 km Elliptical Orbit, Orbital Decay)

(B)

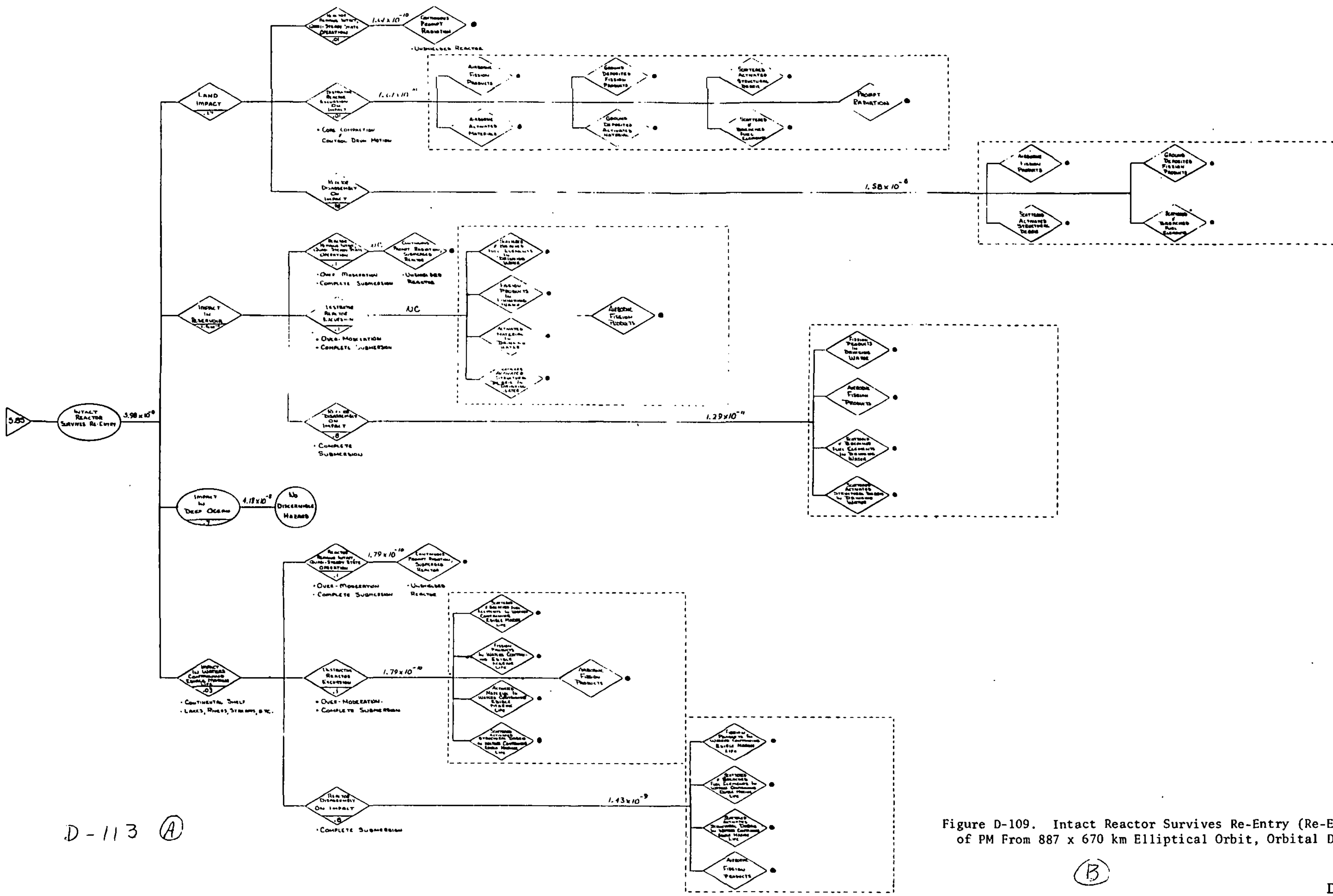
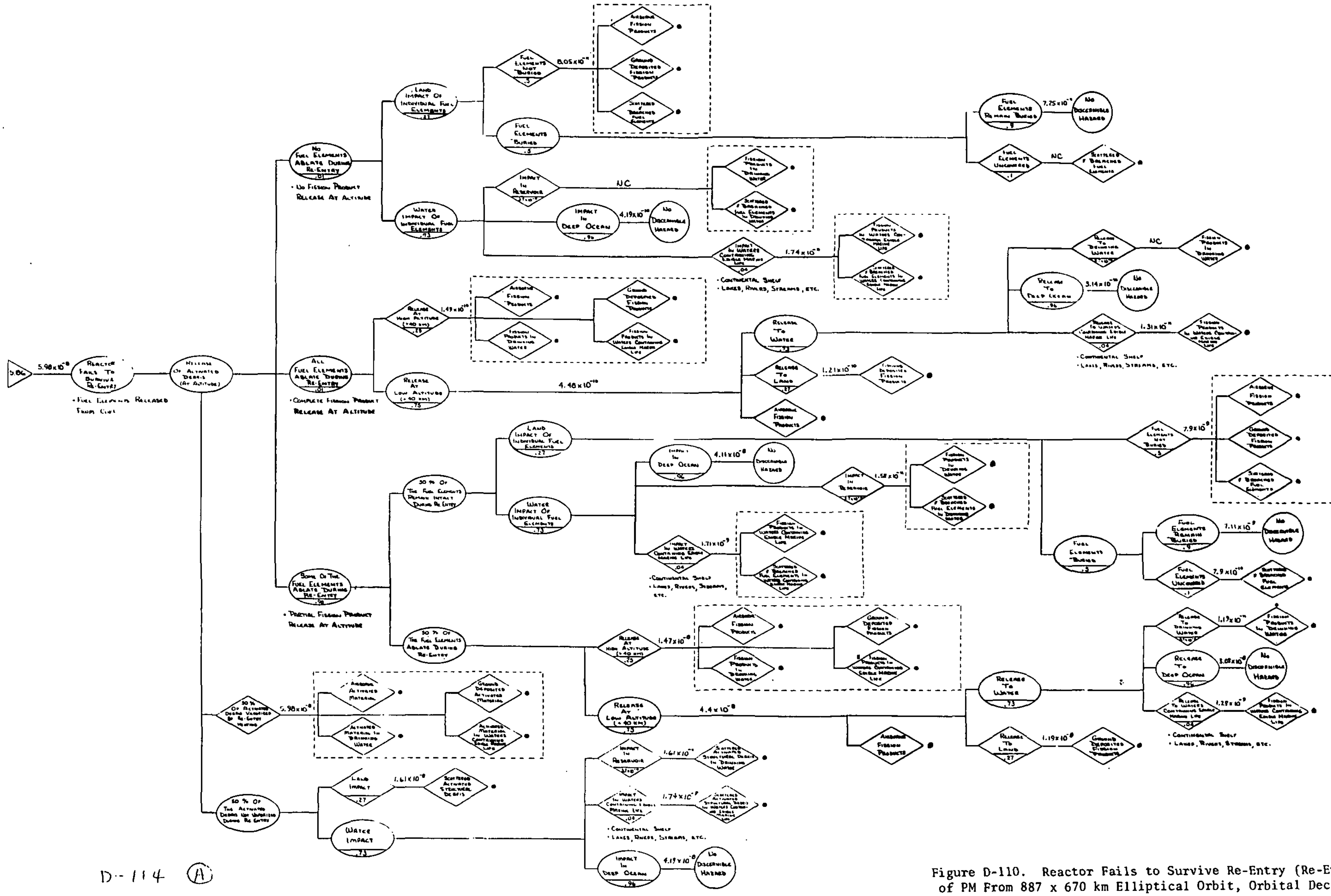


Figure D-109. Intact Reactor Survives Re-Entry (Re-Entry of PM From 887 x 670 km Elliptical Orbit, Orbital Decay)

B



D-114 (A)

Figure D-110. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 887 x 670 km Elliptical Orbit, Orbital Decay)

(B)

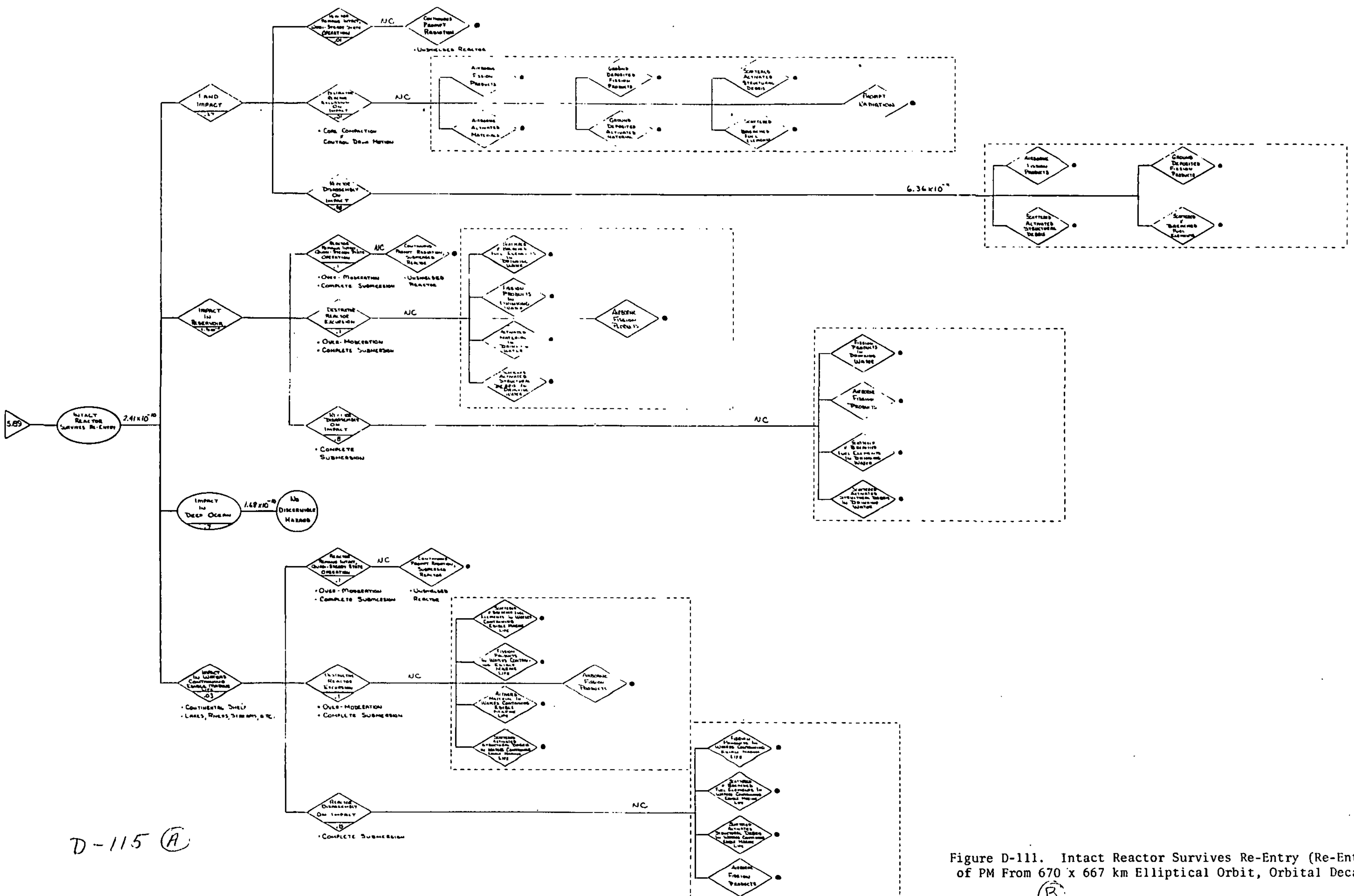


Figure D-111. Intact Reactor Survives Re-Entry (Re-Entry of PM From 670 x 667 km Elliptical Orbit, Orbital Decay)

(B)

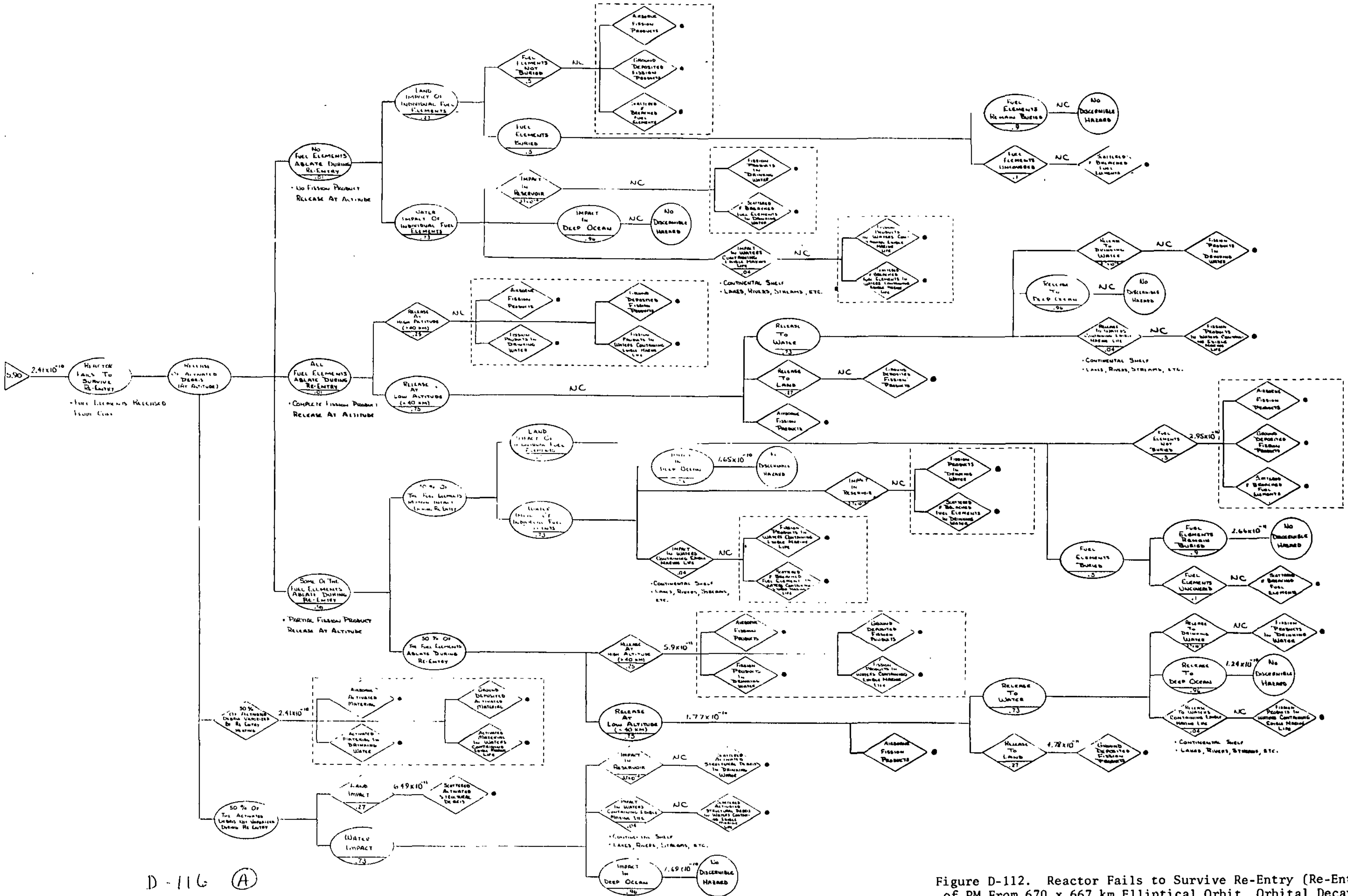
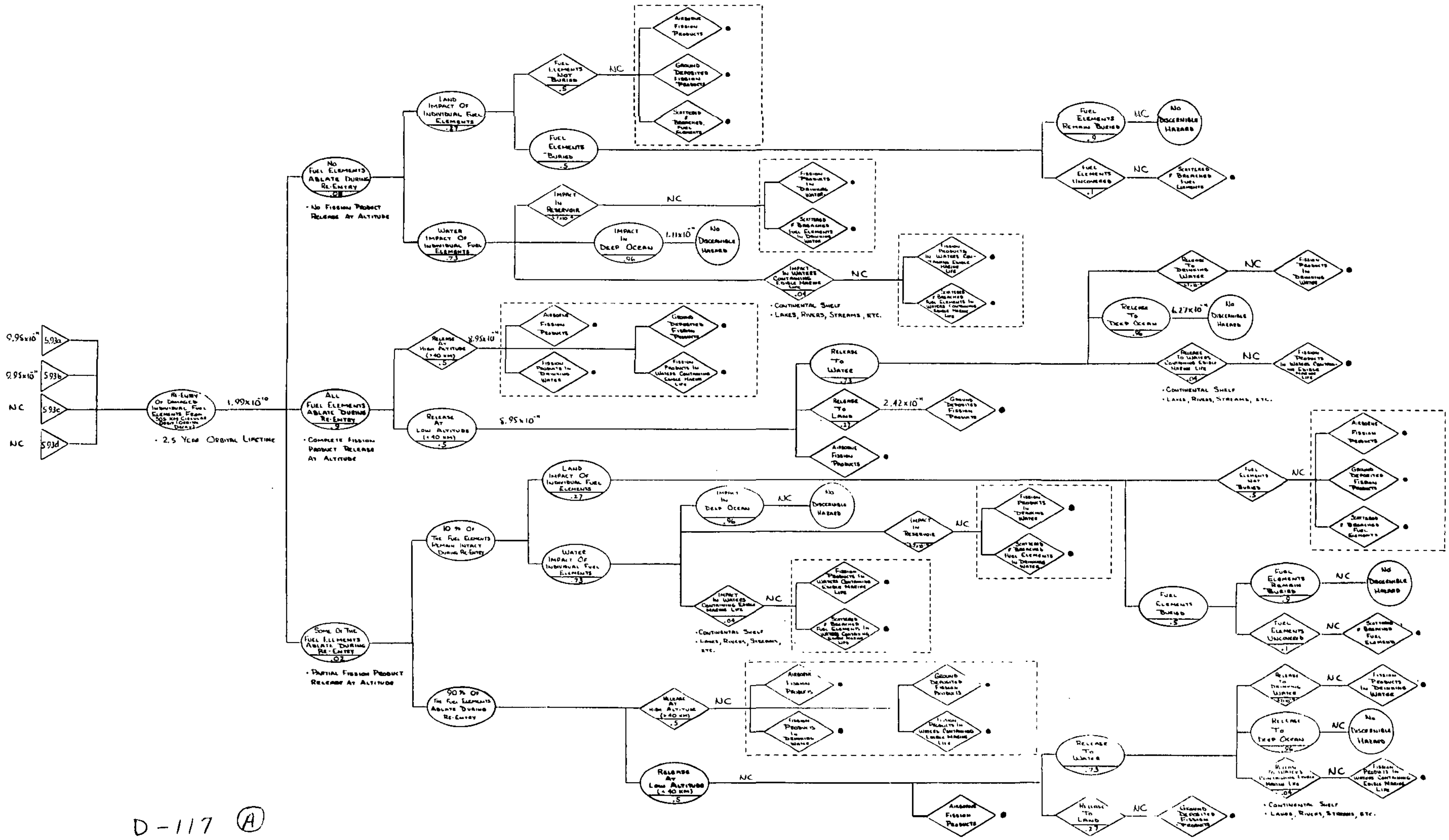


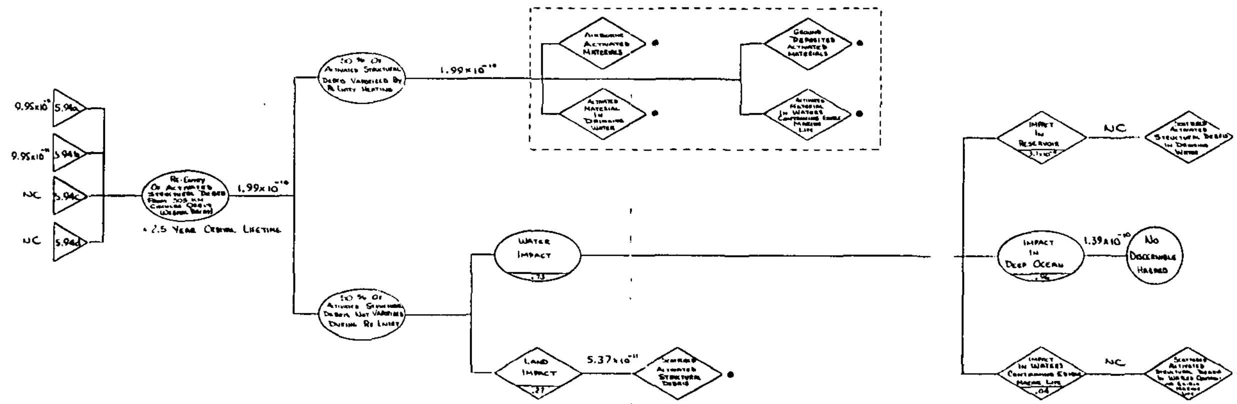
Figure D-112. Reactor Fails to Survive Re-Entry (Re-Entry of PM From 670 x 667 km Elliptical Orbit, Orbital Decay)

(B)



D-117 Ⓐ

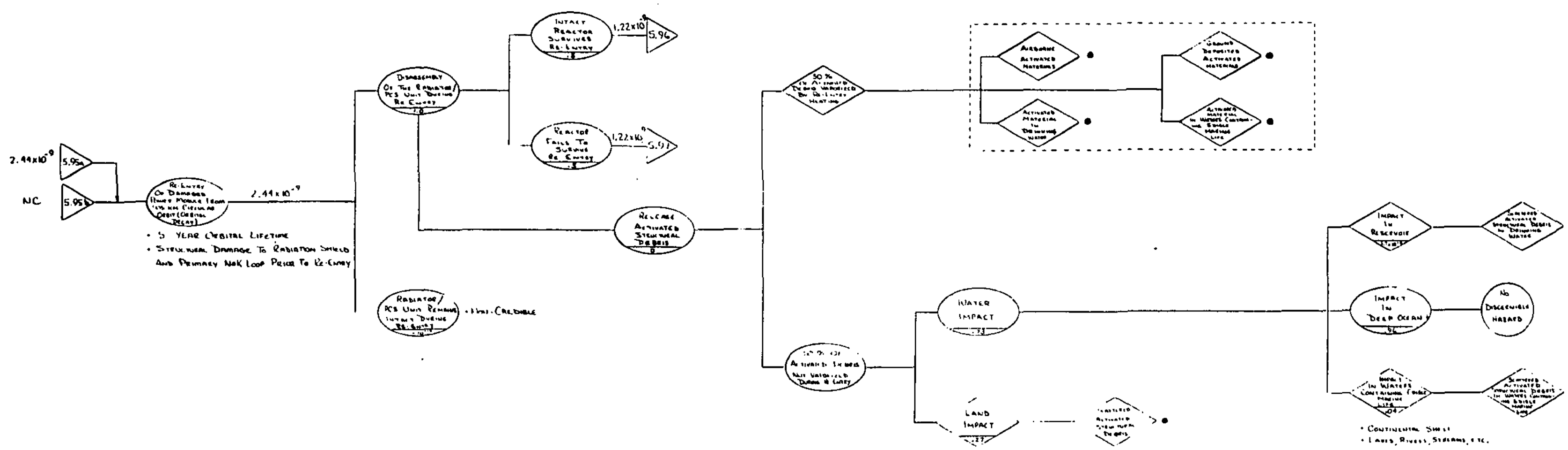
Figure D-113. Re-Entry of Damaged Individual Fuel Elements From 500 km Circular Orbit (Orbital Decay) Ⓑ



D-118 (A)

(B)

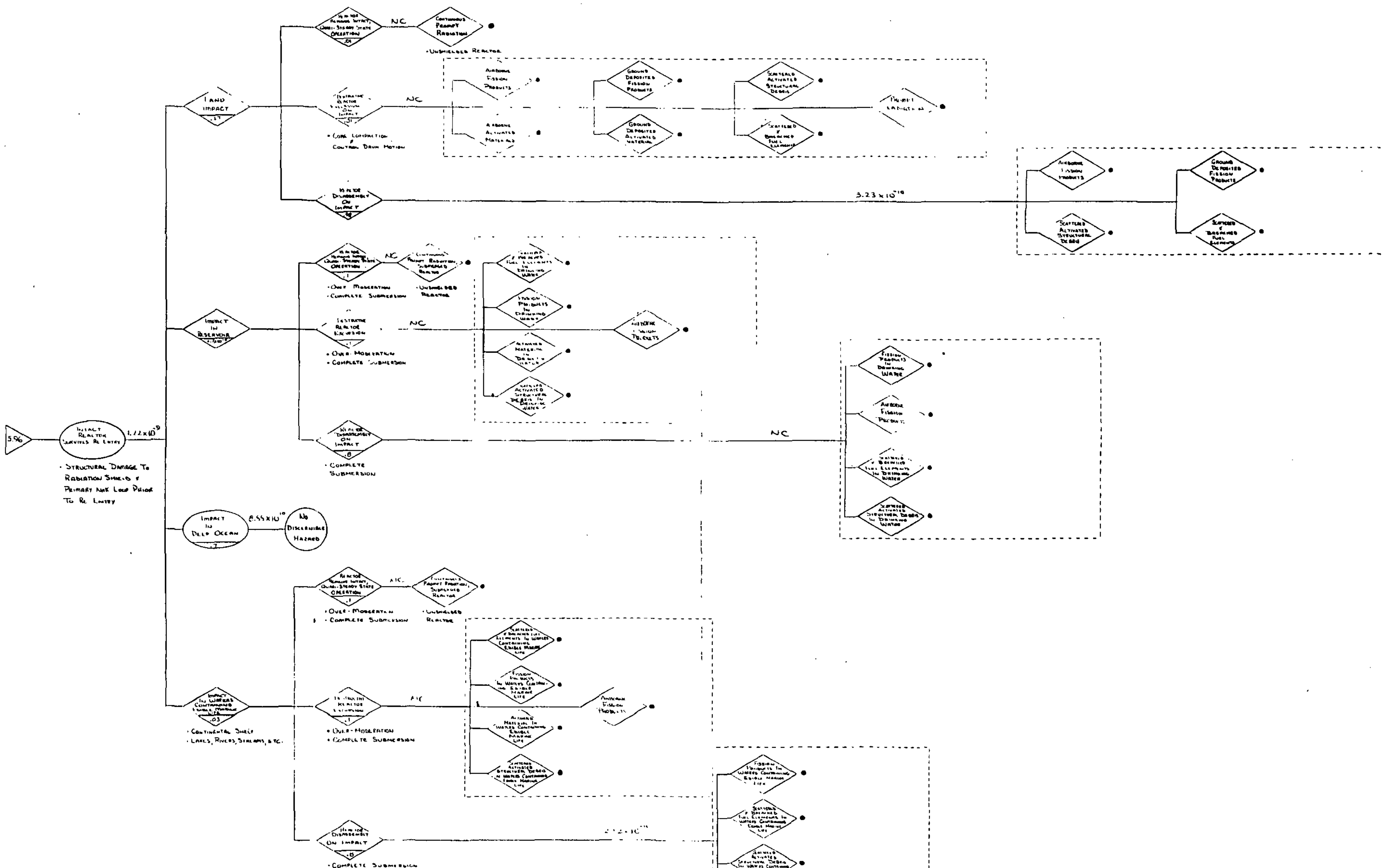
Figure D-114. Re-Entry of Activated Structural Debris From 500 km Circular Orbit (Orbital Decay)



D-119 (A)

Figure D-115. Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay (Structural Damage to Radiation Shield & Primary NaK Loop Prior to Re-Entry)

(B)



D-120 (A)

Figure D-116. Intact Reactor Survives Re-Entry (Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay/ Structural Damage to Radiation Shield & Primary NaK Loop Prior to Re-Entry)

(B)

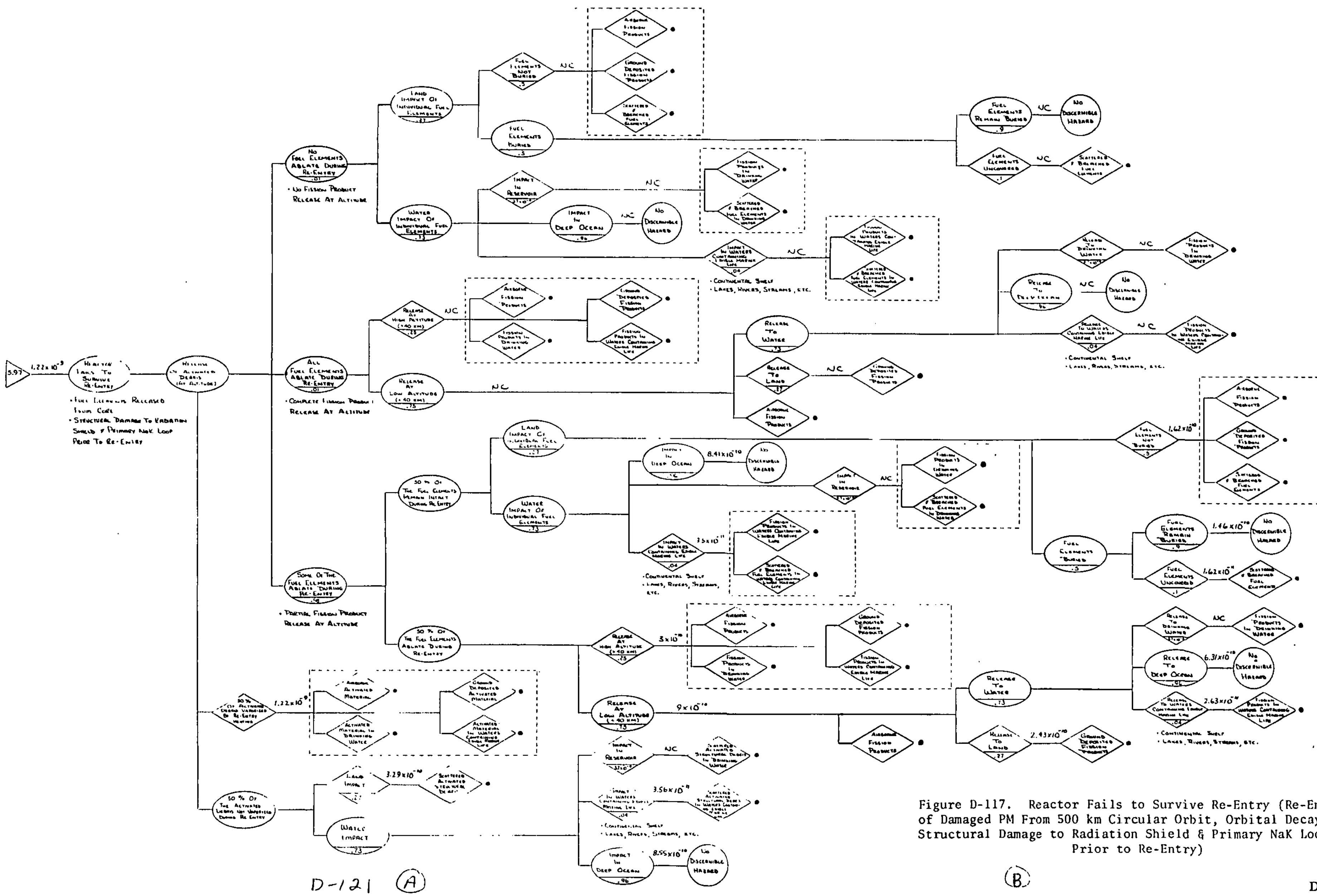
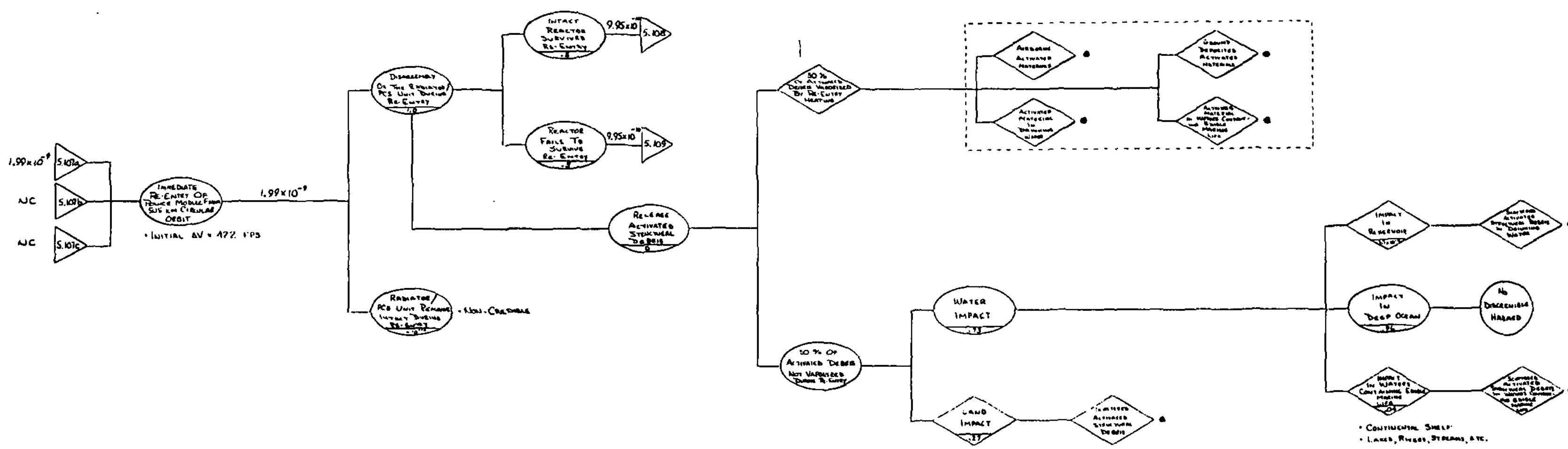


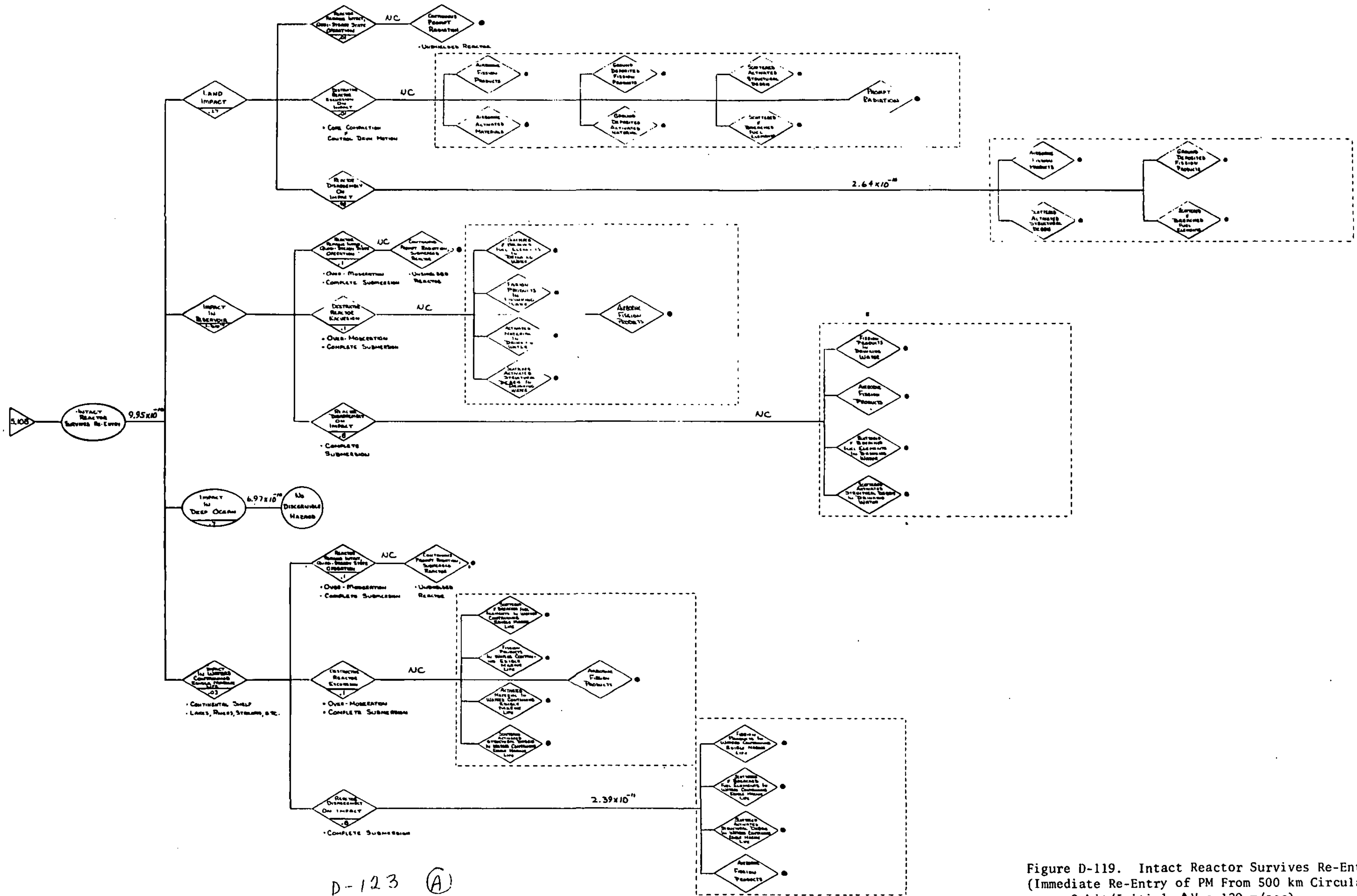
Figure D-117. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged PM From 500 km Circular Orbit, Orbital Decay/ Structural Damage to Radiation Shield & Primary NaK Loop Prior to Re-Entry)



D-122 (A)

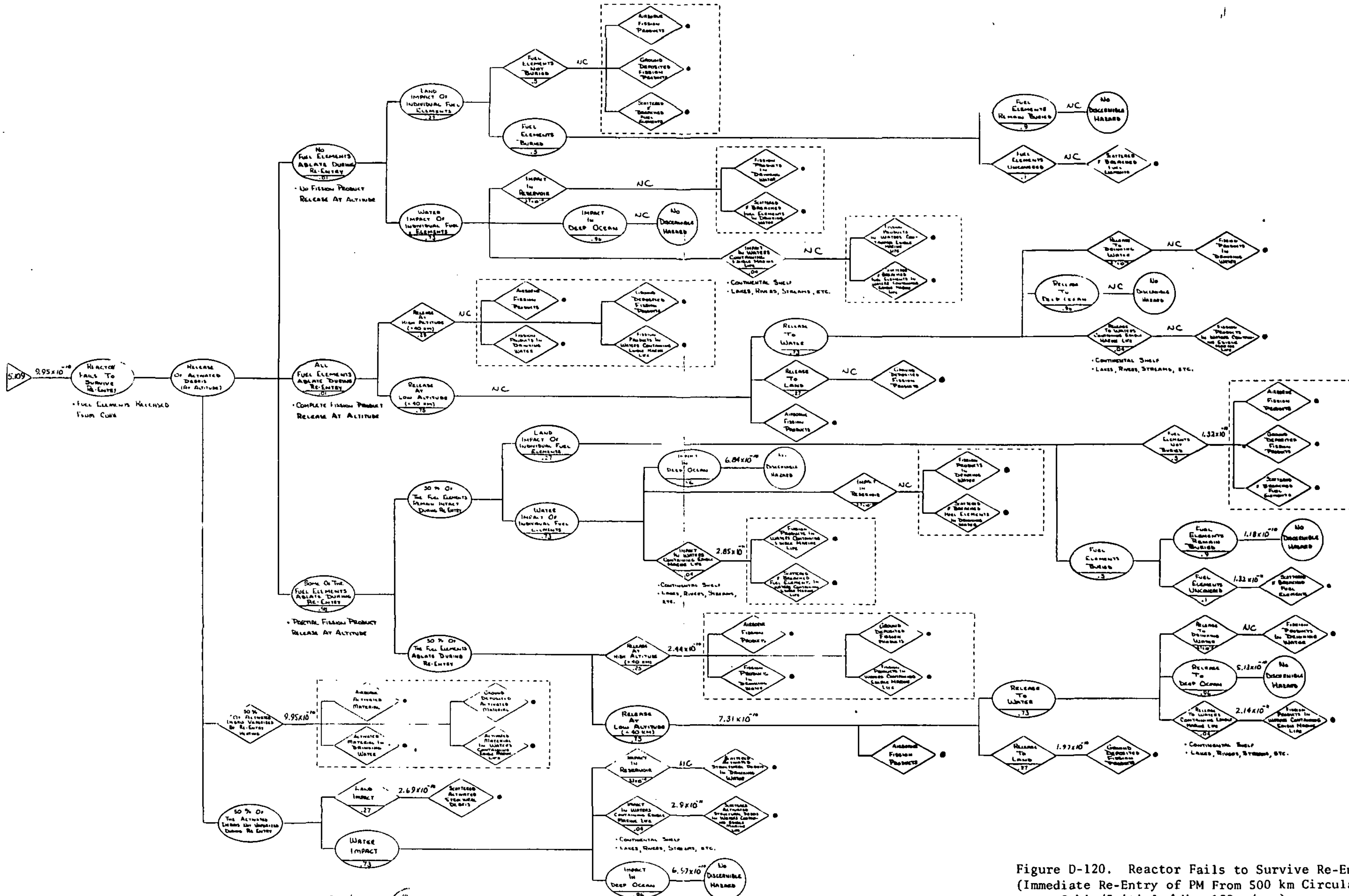
(B)

Figure D-118. Immediate Re-Entry of PM From 500 km Circular Orbit (Initial ΔV = 129 m/sec)



D-123 (A)

Figure D-119. Intact Reactor Survives Re-Entry (Immediate Re-Entry of PM From 500 km Circular Orbit/Initial ΔV = 129 m/sec) (B)



D-124 (A) (B)

Figure D-120. Reactor Fails to Survive Re-Entry (Immediate Re-Entry of PM From 500 km Circular Orbit/Initial ΔV = 129 m/sec)

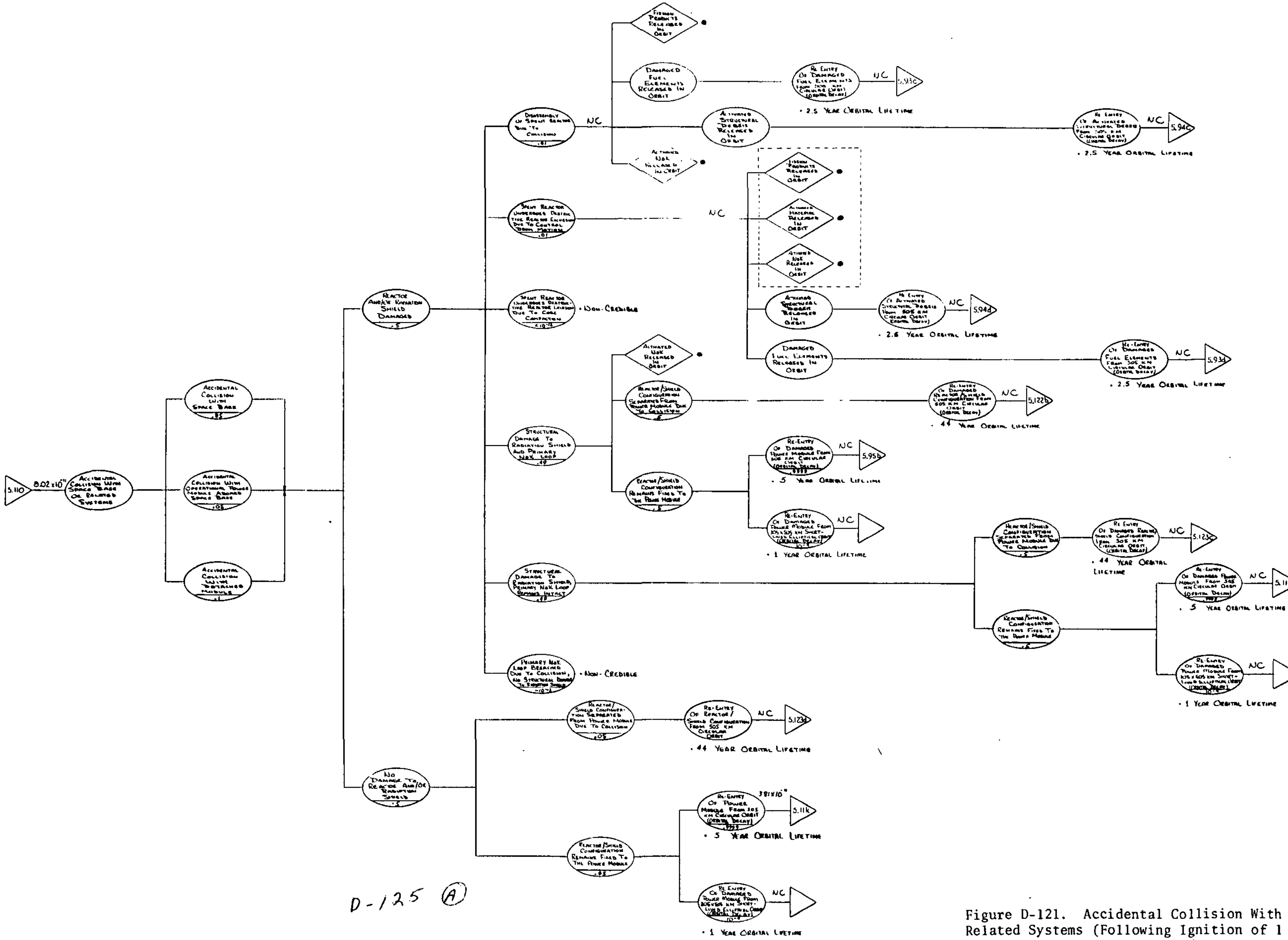


Figure D-121. Accidental Collision With Space Base or Related Systems (Following Ignition of 1 Rocket for Transfer Burn)

(B)

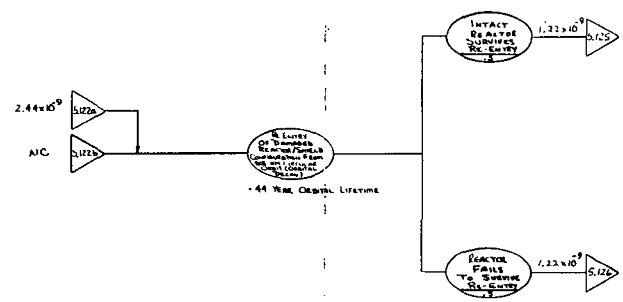


Figure D-122. Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay (Structural Damage to Radiation Shield & Primary NaK Loop Prior to Re-Entry)

D-126 Ⓐ

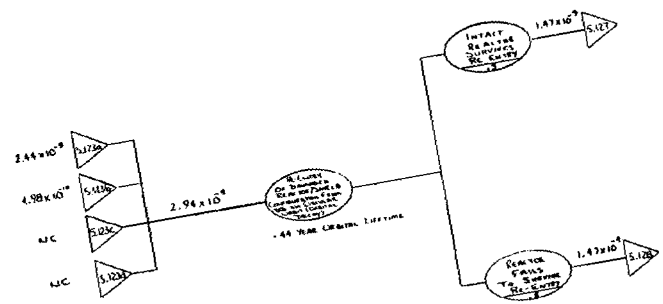


Figure D-123. Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay (Structural Damage to Radiation Shield Prior to Re-Entry)

(B)

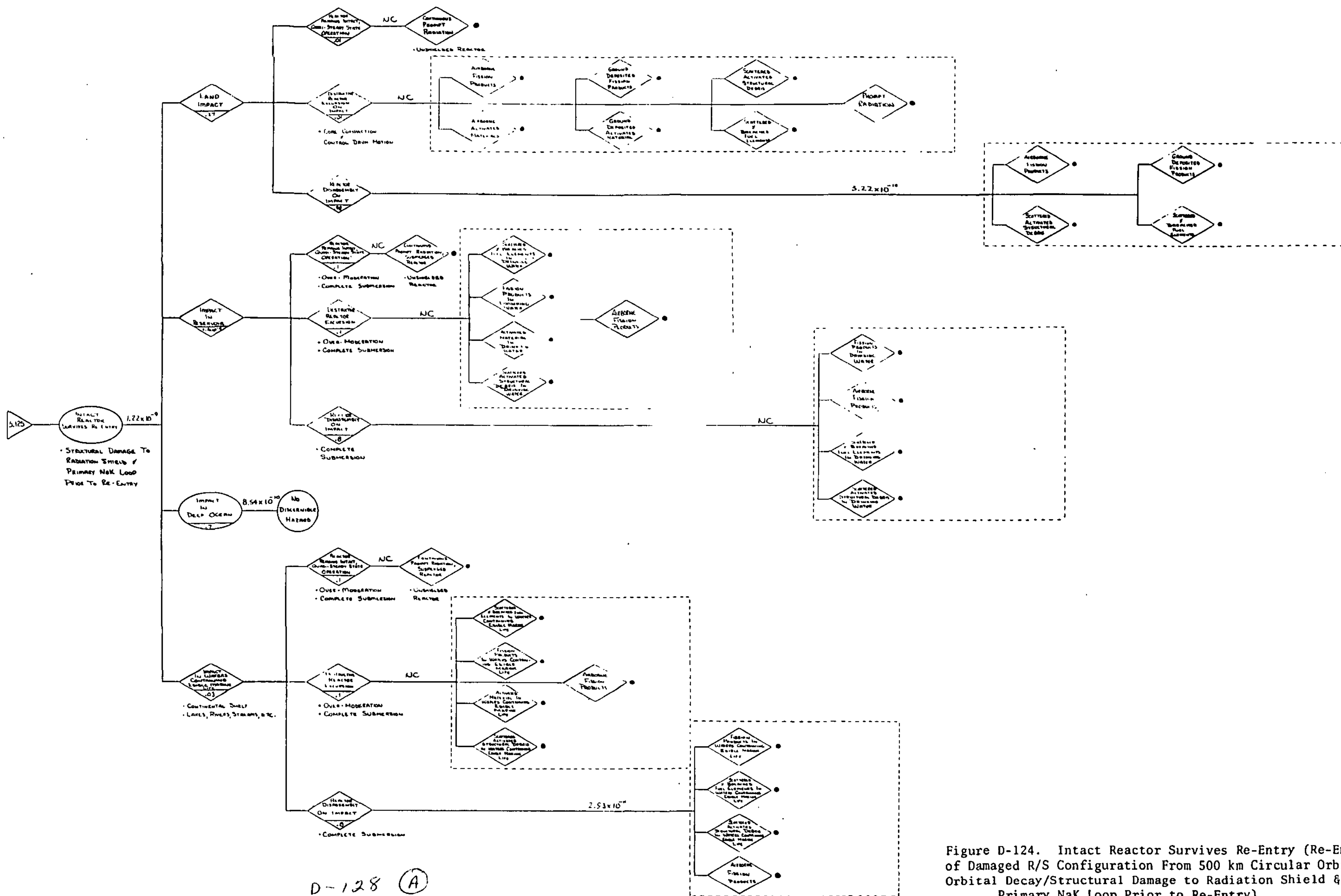
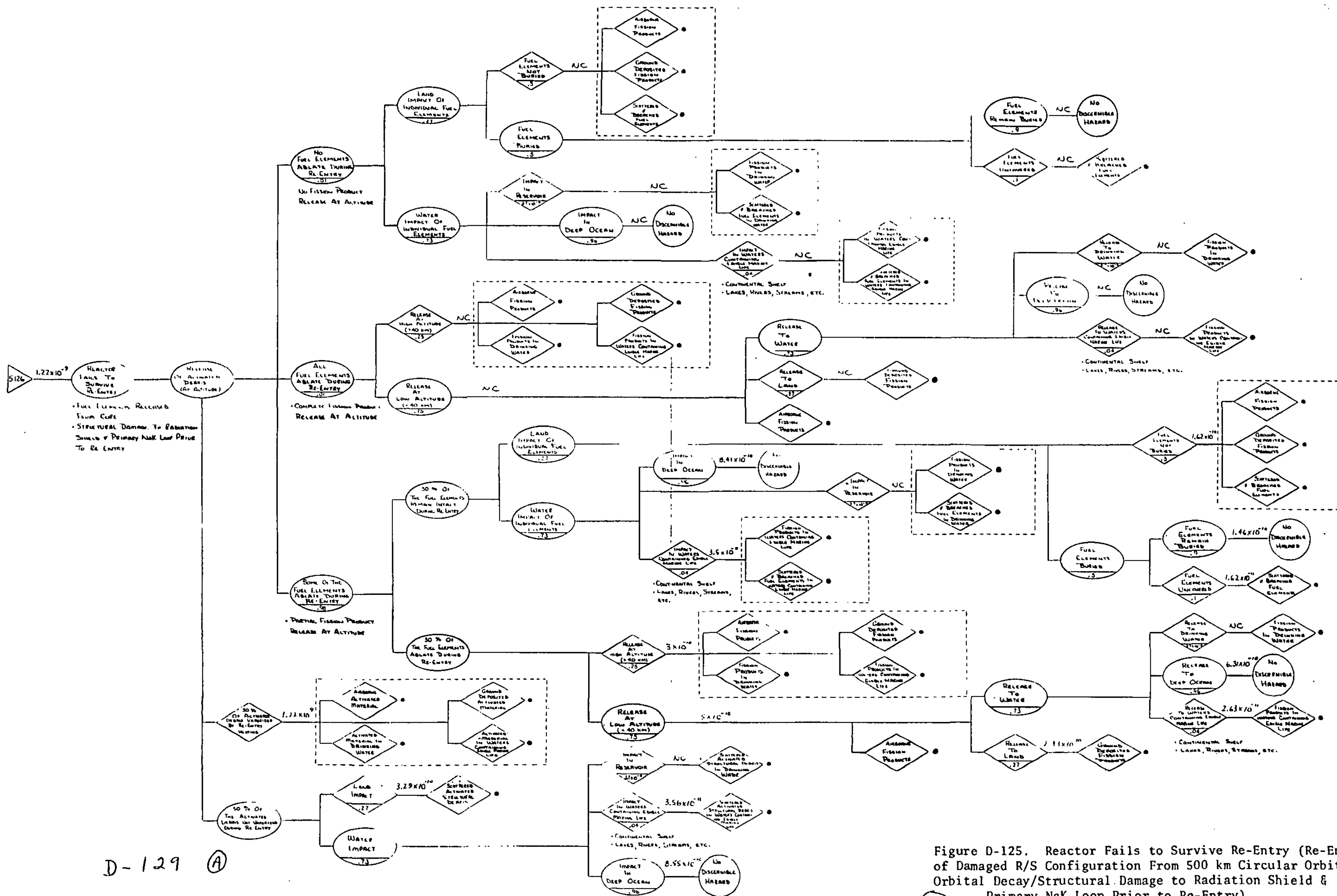


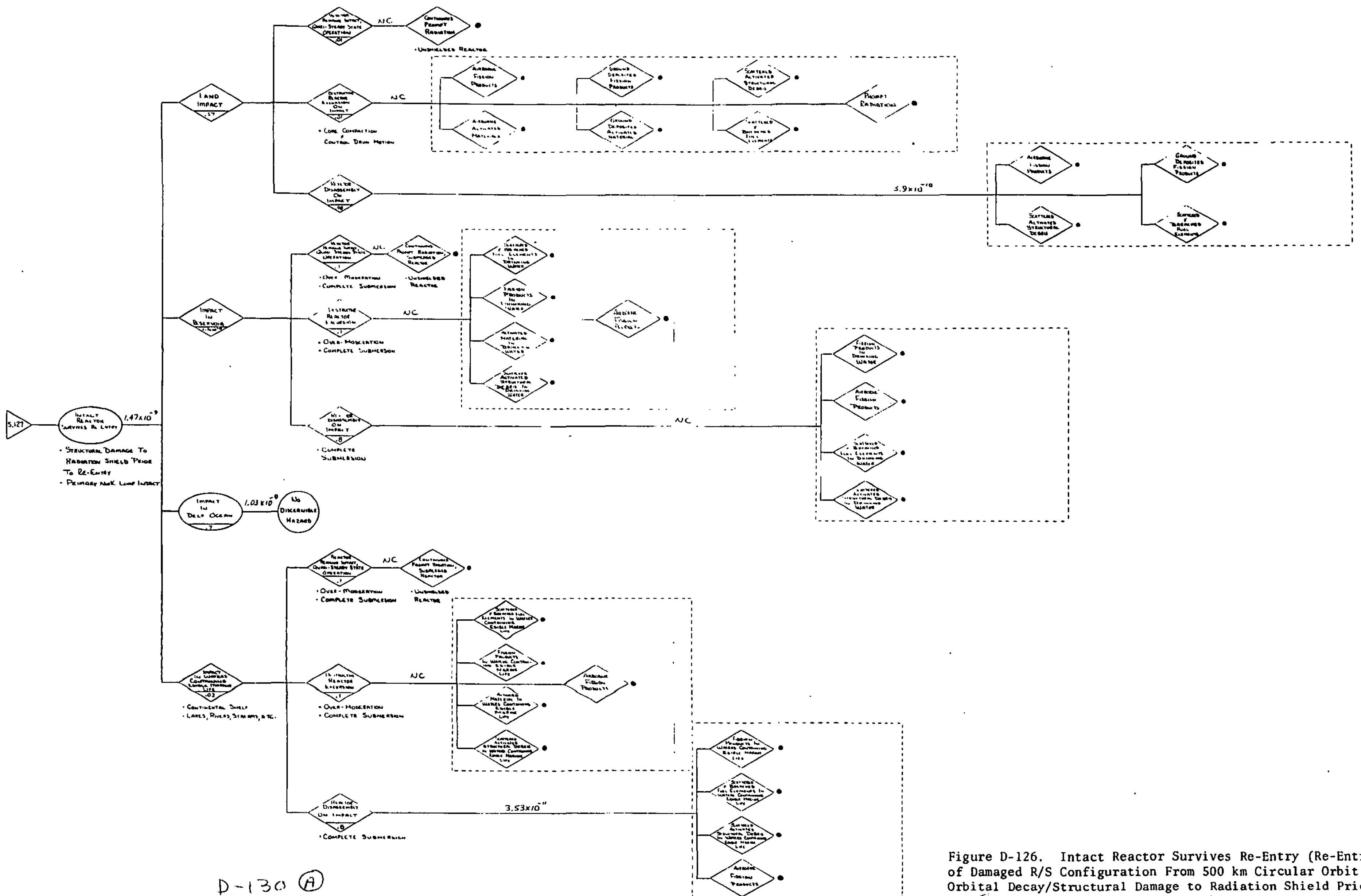
Figure D-124. Intact Reactor Survives Re-Entry (Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay/Structural Damage to Radiation Shield & Primary NaK Loop Prior to Re-Entry)

(B)



D-129 (A)

Figure D-125. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay/Structural Damage to Radiation Shield & (B) Primary NaK Loop Prior to Re-Entry)



D-130 (A)

Figure D-126. Intact Reactor Survives Re-Entry (Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay/Structural Damage to Radiation Shield Prior to Re-Entry) (B)

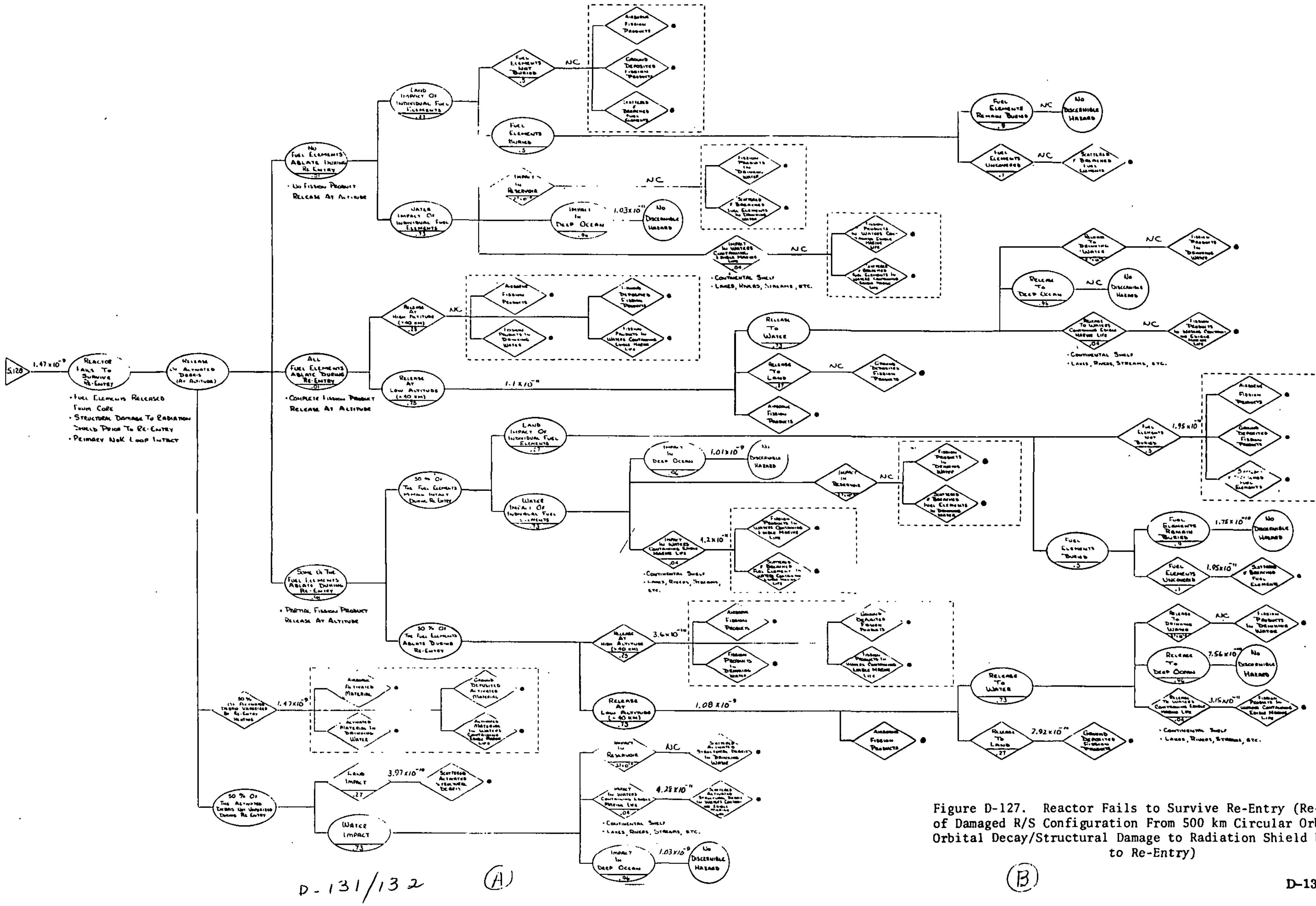


Figure D-127. Reactor Fails to Survive Re-Entry (Re-Entry of Damaged R/S Configuration From 500 km Circular Orbit, Orbital Decay/Structural Damage to Radiation Shield Prior to Re-Entry)

CONVERSION FACTORS
INTERNATIONAL TO ENGLISH UNITS

Physical Quantity	International Units	English Units	Conversion Factor Multiply By
Acceleration	m/sec^2	ft/sec^2	3.281
Area	m^2	ft^2	10.764
		in^2	1550.39
Density	Kg/m^2	lb/ft^3	6.242×10^{-2}
		lb/in^3	3.610×10^{-5}
Energy	Joule	Btu	9.479×10^{-4}
Force	Newton	lbf	2.248×10^{-1}
Length	m	ft	3.281
		nm	5.399×10^{-4}
Mass	Kg	lbm	2.205
Power	watt	Btu/sec	9.488×10^{-4}
		Btu/min	5.691×10^{-2}
		Btu/hr	3.413
Pressure	$Newton/m^2$	Atmosphere	3.413
		lbf/in^2	1.451×10^{-4}
		lbf/ft^2	2.088×10^{-2}
Speed	m/sec	ft/sec (fps)	3.281
Temperature	K	F	$(9/5 - 459.67/t_K)$
Volume	m^3	in^3	6.097×10^4
		ft^3	35.335

GLOSSARY OF TERMS

Abort	Premature and abrupt termination of an event or mission because of existing or imminent degradation or failure of hardware. (In the safety analysis, no distinction is made between an accident and abort.)
Accident	An undesirable unplanned event which may or may not result from a system failure or malfunction.
Airborne Material	Radioactive gases, vapors and particulates released to the air.
Breached	Fuel elements, coolant loops, pressure vessel, core, or radiation shield are (a) physically torn by thermal or mechanical stresses, (b) cut open by fragmentation or (c) split open by internal pressures.
Bulk Damage (Radiation)	Radiation causing atomic displacement in semiconductor devices - sometimes commonly referred to as "crystal" damage.
Contamination	A condition where a radioactive material is mixed or adheres to a desirable substance or where radioactivity has spread to places where it may harm persons, experiments or make areas unsafe.
Control Drum Motion	Rotation of the control drums or drum toward or away from the most reactive position within a reactor. (As used in safety analysis results in a reactor excursion.)
Core Compaction	The act of increasing the density of the core which results in increased reactivity and possible criticality.
Cover Gas	A gas blanket used to provide an inert atmospheric environment around hardware to minimize potential reactions which can give rise to accident situations.
Credible	An event having a relative or cumulative probability of occurence of $> 10^{-12}$.
Criticality	The act of obtaining and sustaining a chain reaction.
Critical Mass	The mass of fissionable material necessary to obtain criticality.
Cumulative Probability	Sometimes referred to as "Mission probability" is the overall probability of a sequence of events occurring (product of "relative probabilities" of the individual events along a path of an abort sequence tree).
Damaged	Same as "Breached".
Decontamination	The removal of undesired dispersed radioactive substances from material, personnel, rooms, equipment, air, etc. (e.g., washing, filtering, chipping).
Destructive Excursion	An excursion (safety analysis assumes $\sim$ 100 MW-sec) accompanied by a complete disassembly of the reactor, a prompt radiation emission and release of fission product gases, vapors and particulates.
Disassembly/Disassembled	Nuclear hardware (e.g., reactor) which has been violently broken or separated into parts and not capable of forming a critical mass.
Disposal	The planned discarding or recovery of nuclear hardware.
Distributed Material	The spread of nuclear fuel and radioactive debris on the earth's surface following impact or destructive excursion.
Dose Guidelines	Established radiation levels used in the nuclear safety analysis for evaluating number of exposures and in determining operating limits and boundaries.
Dosimetry	Techniques used in the measurement of radiation.

GLOSSARY OF TERMS (CONT)

Dynamic Interference	An experiment radiation effect where the flux rate above some threshold (a fraction of the experiment signal-to-noise ratio at maximum sensitivity, for electronic detectors) causes noticeable degradation of data quality.
Early Reactor Disposal	Attempted disposal of the reactor prior to its successful completion of 5 years operational lifetime.
Electrical Power System	All components (heat source, regulation, control, power conversion and radiators) necessary for the development of electrical power. The reactor electrical power system includes all hardware associated with the Power Module with the exception of the Disposal System.
End of Mission	Generally associated with the termination of the mission or flight. Is also used to define those activities involved with disposal and recovery of hardware after intended lifetime.
Excursion	A rapid and usually unplanned increase in thermal power associated with the operation of a power reactor.
Exposure Limit	Total accumulated or time dependent radiation exposure limits imposed on personnel by regulatory agencies or limits which preclude equipment damage.
Fission Products	The nuclides (quite often radioactive) produced by the fission of a heavy element nuclide such as U-235 or Pu-239.
Fuel	Fissionable material in a reactor or radioisotopes in a heat source used in producing energy.
Fuel Element/Capsule	A shaped body of nuclear fuel prepared for use in a reactor or heat source. Common usage involves some form of encapsulation.
Fuel Element Ablation	Fuel element clad and/or fuel removed by reentry heating, releasing fission products to the atmosphere.
Fuel Element Burial	Individual fuel elements beneath the ground surface completely covered by soil.
Gallery	The compartment of the reactor shield which houses the major primary loop components.
Ground Deposited Particles	Particles deposited on the ground from radioactive fallout.
Hazard	An existing situation caused by an unsafe act or condition which can result in harm or damage to personnel and equipment.
Hazard Source	The location and/or origin of the hazard.
Immediate Reentry	Very early reentry of the reactor (e.g., misaligned thrust vector which causes firing of the reactor disposal rockets toward earth resulting in 1-2 day reentry).
Impact in Deep Ocean	Reentering and/or impact of nuclear material in the ocean, beyond the Continental Shelf where contamination of the food chain is extremely remote.
Impact in Reservoir	Reentering and/or impact of nuclear material in reservoir containing potable drinking water.
Impact in Water Containing Edible Marine Life	Reentering and/or impact of nuclear material on the Continental Shelf or in a body of water such as a lake, river or stream where contamination of the food chain is likely.
Intact Reentry/Reactor	A nuclear system that retains its integrity upon impact and in the case of a reactor is capable of undergoing an excursion.
Integrated/Cumulative Dose	The total dose resulting from all or repeated exposures to radiation.
Interfacing Vehicle	Any defined module, spacecraft, booster or logistic vehicle which may have an interaction with the Manned Space Base.

GLOSSARY OF TERMS (CONT)

Ionization Damage	Radiation causing surface damage in materials (e.g., the fogging of film).
Land Impact	Nuclear hardware which impacts land at terminal velocities following reentry and lower velocities during prelaunch or early in the launch/ascent phase.
Loss of Coolant	Loss of organic or liquid metal coolant in reactor coolant loops due to failure/accident.
Mission Support	Supporting functions provided the Space Base Program by ground personnel and interfacing vehicles throughout all mission phases.
Moderator	Material used in a nuclear reactor to slow down neutrons from the high energies at which they are released to increase the probability of neutron capture: Water and hydrogen are moderators in a thermal reactor.
NaK-78	An alloy of sodium (22% by weight) and potassium (78%) used as a liquid metal heat transfer fluid.
No Discernible Hazard	Represents no hazard to the general populace.
Non-credible	An event having a relative or cumulative probability of occurrence of $< 10^{-12}$. Considered not worthy of concern.
Non-destructive Excursion	A temperature excursion which may rupture the primary coolant loop and release fission products to the environment but - leaves the reactor shield essentially intact.
Normal Operations	Planned and anticipated mission activities and events.
Over Moderation	Immersion of reactor in an hydrogenous medium (moderator) resulting in increased neutron reflection into the core causing a reactor excursion.
Permanent Shutdown	Enacting provisions which preclude reactor criticality under all foreseeable circumstances.
Poison	A material that absorbs neutrons and reduces the reactivity of a reactor.
Power Module	The complete reactor/shield, radiator, power conversion system and disposal system unit as provided on the Space Base.
Premature Reentry	Any reentry of the reactor from Earth orbit with orbital lifetimes less than the planned (1167 year) orbital decay time of the 990 km disposal altitude.
Pre-poison	A poison which is added to the reactor fuel for purposes of controlling reacticity. Sometimes referred to as "burnable poison".
Prompt Radiation	The neutron and gamma radiation released coincident with the fission process as opposed to the radiation from fission product decay. Commonly associated with an excursion event.
Quasi-Steady State	A term used to describe the condition when a reactor periodically goes critical and then subcritical due to water surging in and out of the core.
Radiological Consequences	The radiation exposure effect on personnel and the ecology from a radiation release accident or event.
Radiological Hazards	Hazards associated with radiation as differentiated from other sources.
Radiological Risk	The term used to define the average number of people anticipated to be affected by radiation in a given mission or phase thereof.
Random Reentry	The uncontrolled non-directed reentry of a vehicle from orbit.
Reactivity	A measure of the departure of a reactor from critical such that positive values correspond to reactors super-critical and negative values to reactors which are sub-critical. (Usually expressed in multiples of a dollar.)

GLOSSARY OF TERMS (CONT)

Reactor Fails to Survive Reentry	Reactor/shield is completely disassembled by reentry heating, releasing individual fuel elements and structural debris to the atmosphere.
Reactor Survives Reentry	Reactor is not disassembled by reentry heating; radiation shield may be damaged.
Reactor/Shield	A system containing the reactor, control drums, gallery and surrounding LiH and Tungsten shield.
Relative Probability	Probability of the occurrence of a particular event given a defined set of choices.
Repair/Replacement	Consists of (a) physically repairing all faulty systems, or (b) complete replacement of the faulty system(s).
Ruptured	Same as "Breached".
Safety	Freedom from chance of injury or loss to personnel, equipment or property.
Safety Catastrophic	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will severely degrade system performance, and cause subsequent system loss, death, or multiple injuries to personnel (SPD-1A).
Safety Critical	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will cause equipment damage or personnel injury, or will result in a hazard requiring immediate corrective action for personnel or system survival (SPD-1A).
Safety Marginal	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will degrade system performance but which can be counteracted or controlled without major damage or any injury to personnel (SPD-1A).
Safety Negligible	Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will not result in minor system degradation and will not produce system functional damage or personnel injury (SPD-1A).
Scram System	A separate, possibly automatic, mechanism used to rapidly shut down a reactor.
System Safety	The optimum degree of risk management within the constraints of operational effectiveness, time and cost attained through the application of management and engineering principles throughout all phases of a program.
Space Base Program	All aspects of the Space Base mission including all prime and support hardware and personnel both on the ground, at sea or in orbit, which are required throughout all mission phases.
Space Debris	Uncontrolled radioactive or non-radioactive man-made objects in space; these objects may present collision and radiation hazards to earth orbital missions.
Space Shuttle	The manned vehicle used for the transportation of cargo to and from earth orbit. A separately launched vehicle (booster) on which the Shuttle is placed provides the initial first stage thrust.
Source Terms	Characterization of a radiation hazard with regard to (a) location, (b) magnitude, and (c) exposure mode.
Tracer	Material in which isotopes of an element may be incorporated to make possible observation of the course of the element through a chemical, biological or physical process.